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ANALYSIS OF HISTORICAL EVIDENCE OF CLIMATE CHANGE IN WESTERN AND NORTHERN CANADA

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INTRODUCTION

Analysis of historical climatic evidence, now in progress at the Universities of Manitoba and Winnipeg, are based entirely upon Hudson's Bay Company records. The objective is to thoroughly explore the utility of this valuable historical climatic resource before other potential Canadian historical sources are examined (Catchpole 1980). This report deals with three major aspects of this research: (1) a study of ice conditions on northern rivers and seas; (2) a reconstruction of dates of first snowfall and first frost in the Hudson Bay region; (3) the development of a computer-coding system for the retrieval and analysis of climatic information in the Hudson's Bay Company post journals. The immediate goal of this report is to present results which have been obtained to date and to outline the methods of analysis being applied. Interpretation of these and subsequent findings in the light of knowledge of climatic change in the historical period will be presented in a later report.

ICE CONDITIONS ON NORTHERN RIVERS AND SEAS

The historical evidence of climatic conditions largely comprises descriptive commentaries on weather and environmental conditions contained in written sources. The records of the Hudson's Bay Company are full of climatic information, mainly because they were written in an environment where the vagaries of climate imposed severe restrictions on life. The Company's diarists were not instructed to record weather routinely and systematically, but the rigours of weather in this subarctic environment determined that their diaries frequently mention weather. Casual observers, lacking meteorological instruments, readily perceive those weather elements that are tangible in nature, and references to them commonly occur in their diaries

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and journals. Thus, descriptions of ice abound in the historical sources and have proven a rich resource for climatic study. Current research at the University of Manitoba is largely focused on annual fluctuations in ice conditions. The two aspects of ice research to be examined below include: (1) a study of dates of freezing and breaking of river estuaries in the James Bay region; (2) a study of sea-ice intensity in Hudson Strait. The first of these studies is based on information in the post journals, the second utilizes log books of the Company's ships.

Dates of Freezing and Breaking of James Bay Estuaries

Content analysis has been used to derive dates of first freezing and first breaking of water bodies from Hudson's Bay Company post journals (Moodie and Catchpole 1975). Records of annual dates were derived from information on Churchill Factory (1718 to 1866), York Factory (1714 to 1850), Moose Factory (1736-1870) and Fort Albany (1721 to 1867). Many journals were kept after 1870, but until recently the Company's archival policy prevented consultation of post-1870 journals. Therefore, published records of dates extend from the time of commencement of each journal to no later than 1870. Initial goals of the subsequent phase of the freezing and breaking study were:

(1) to derive post-1870 dates from those journals that continue into the twentieth century, thereby linking historical dates with the period covered by modern observations. Fortunately, a change in the Company's archival policy permitted consultation of the post-1870 journals;
(2) to extend the network of dated estuaries on the coast of Hudson Bay by deriving dates from Severn House and Eastmain House post journals (Figure 1).

When these parts of the study were completed, it was apparent that the trends at Moose Factory, Fort Albany and Eastmain were highly homogeneous. This prompted a third objective - a combination of dates from these three places in order to derive *annual means dates* of freezing and breaking for the James Bay region.

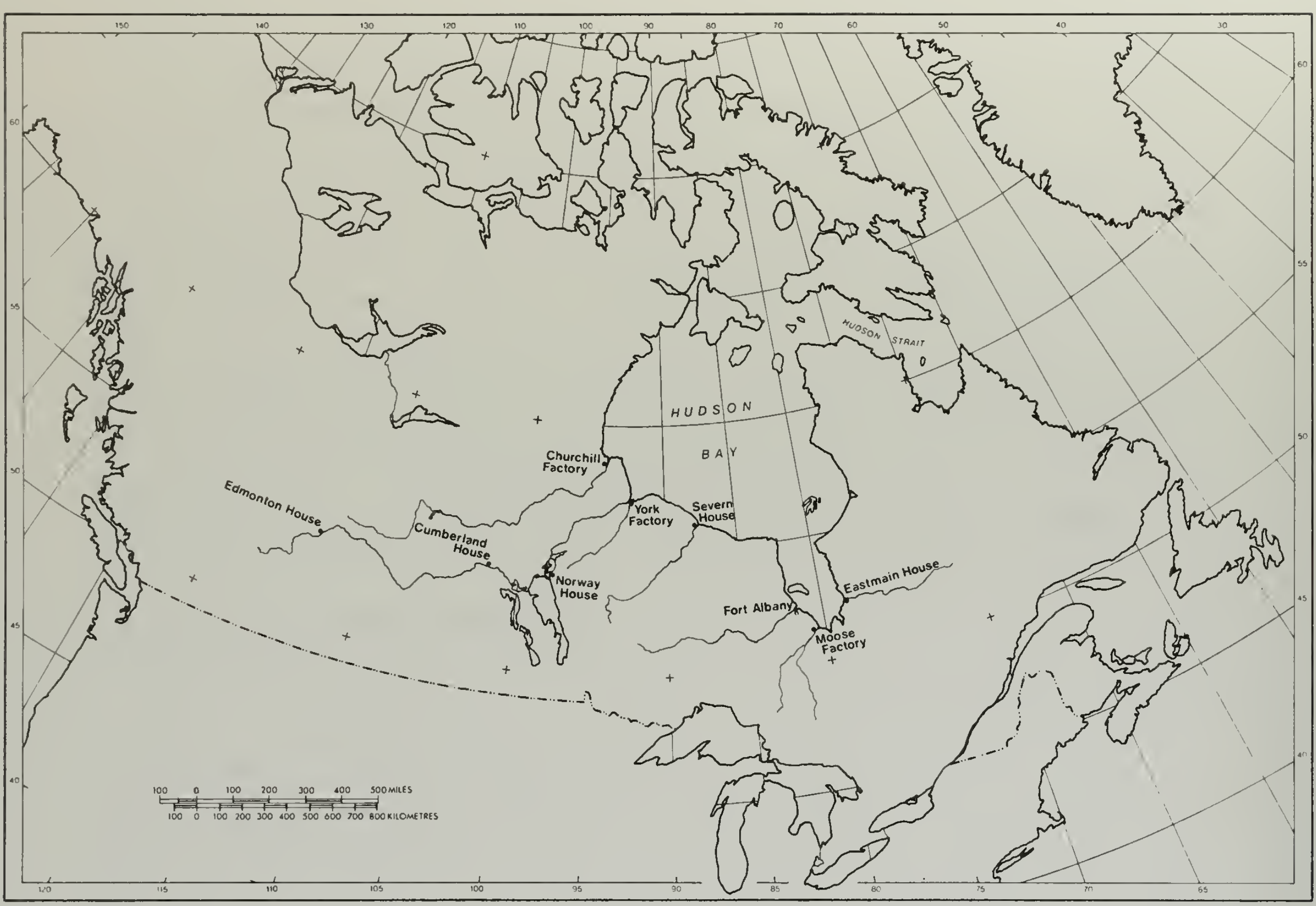

FIGURE 1: *Location map.*

Post-1870 Dates

Of the four journals analyzed previously, Albany alone was sufficiently continuous beyond 1870 to justify an extension of dating into the twentieth century. Albany journals continued to 1921, with only sporadic interruptions. Content analysis was applied without modification to the journals kept between 1871 and 1921. Figure 2 shows dates of first partial freezing, first complete freezing, and first breaking at Albany. With the addition of these dates, the Albany record of freezing and breaking now extends over 200 years.

Eastmain and Severn

The Eastmain journal spans two periods, 1743 to 1837 and 1893 to 1921. The Severn record commences in 1761 and continues intermittently until 1897. Eastmain House was located on the east side of James Bay and was approximately 230 km east of Albany and 160 km northeast of Moose Factory. It was on the shore of the estuary of the Eastmain River. Severn House was located on the north shore of the estuary of the Severn River, some 22 km inland from the Hudson Bay coast.

Content analysis must be specifically applied to each estuary since it is adapted to a consideration of local geographical conditions. Consequently, modified forms of the method were developed for Eastmain and Severn. Modifications involved the identification of five dating places and zones in the Eastmain estuary and four in the Severn estuary. Figures 3 and 4 show the annual dates of freezing and breaking for Eastmain and Severn.

James Bay Regional Means

There is a high degree of homogeneity between dates derived at Moose and Albany (Moodie and Catchpole 1975). This homogeneity was interpreted as a verification of the validity of these historical dates, but it also indicates that the Moose and Albany dates can be combined to derive means representative of the west coast of James Bay. Similar homogeneity tests were applied to the Eastmain and Severn dates using the Pearson product-moment correlation coefficient. These tests indicate that freezing and breaking dates at Eastmain and Severn are significantly correlated with those at Albany and Moose, but dates of first partial freezing at Eastmain and Severn are not significantly correlated (Table 1). The means, standard deviations and extremes of these dates also demonstrate homogeneity among the three estuaries of James Bay (Table 2). However, the Severn means are substantially different from

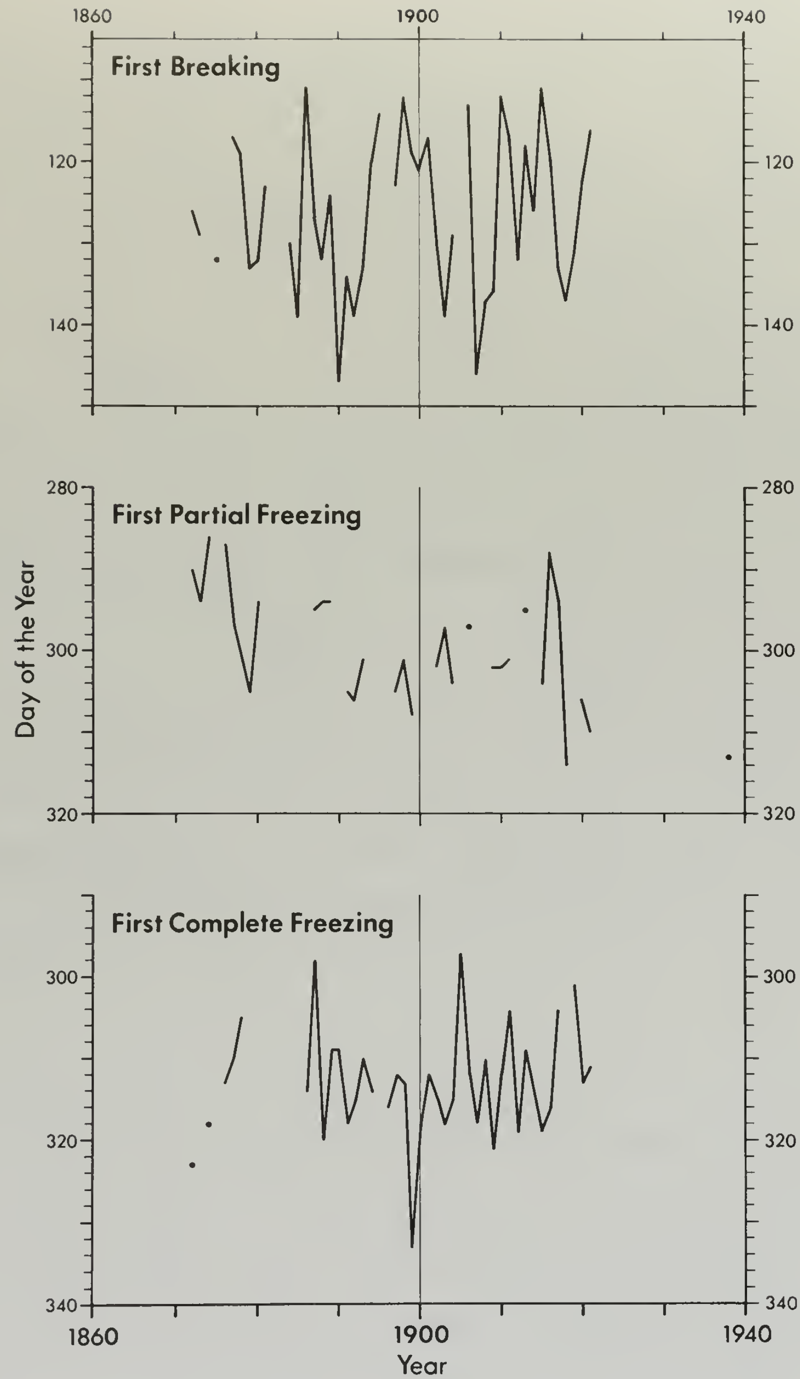

FIGURE 2: *Dates of first breaking, first partial freezing and first complete freezing at Fort Albany, 1871 to 1940.*

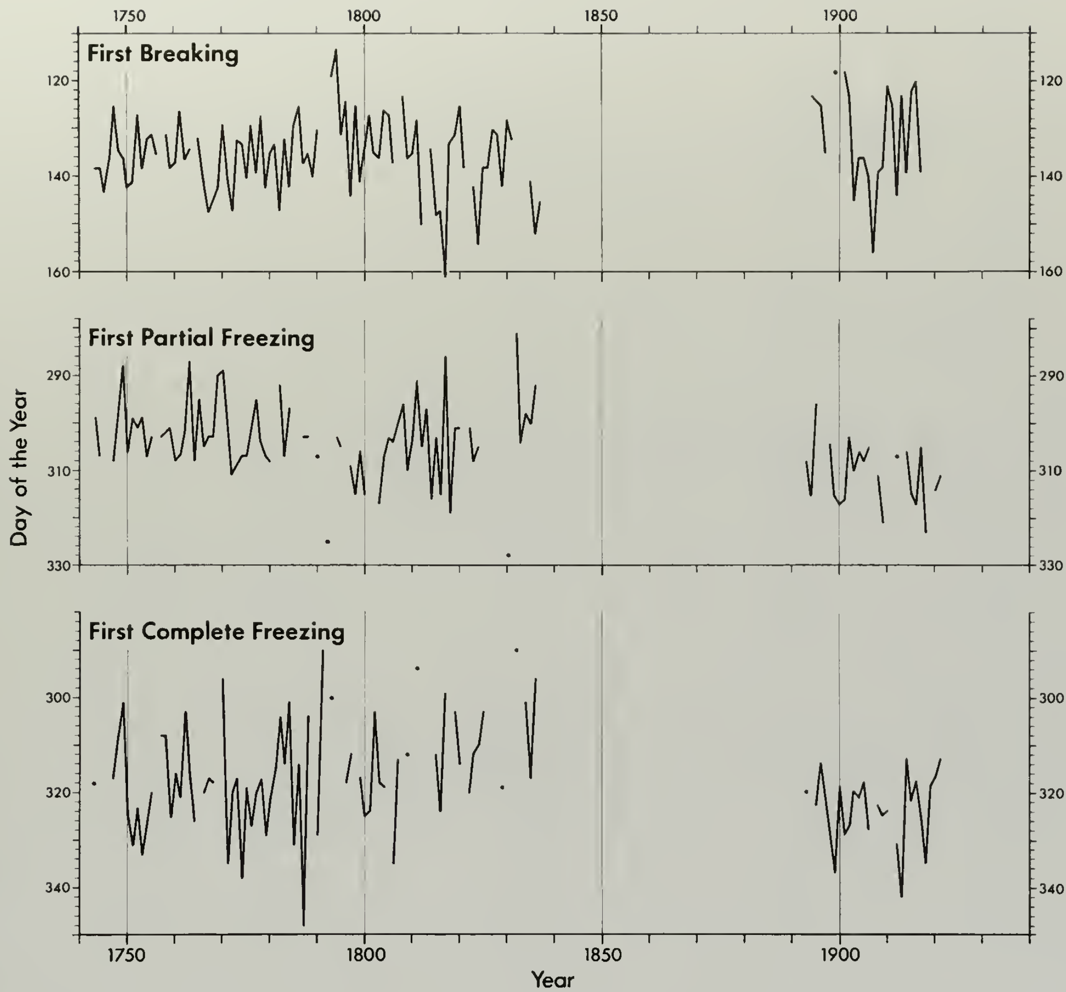

FIGURE 3: *Dates of first breaking, first partial freezing and first complete freezing at Eastmain House, 1743 to 1921.*

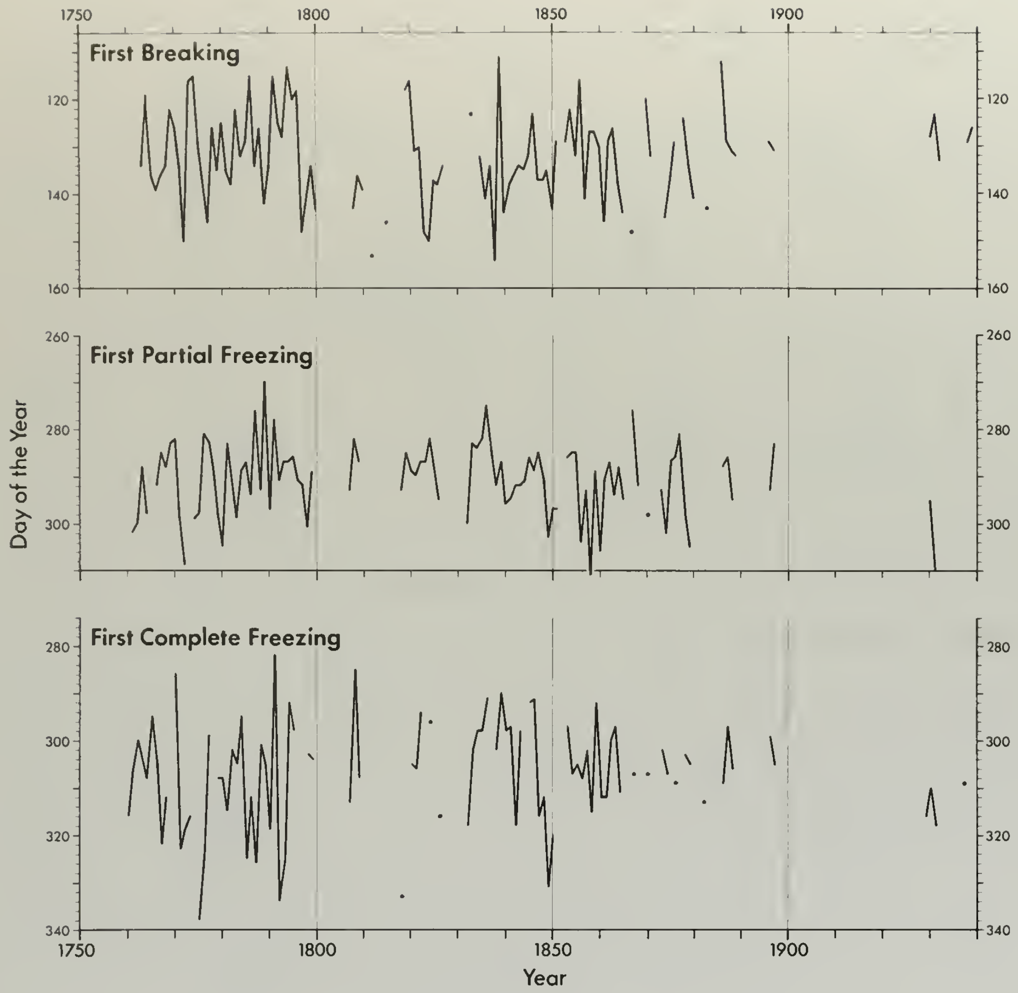

FIGURE 4: *Dates of first breaking, first partial freezing and first complete freezing at Severn House, 1761 to 1939.*

TABLE 1: *CORRELATION COEFFICIENTS BETWEEN ICE DATES AT SELECTED ESTUARIES. COEFFICIENTS REQUIRED FOR SIGNIFICANCE AT THE 0.01 LEVEL ARE GIVEN IN PARENTHESIS.*

FIRST PARTIAL FREEZING

	Moose	Albany	Severn	York 1	York 2	Churchill 1	Churchill 2
Eastmain	0.59	0.51	0.36	0.34	0.22	0.12	0.16
	(0.28)	(0.27)	(0.37)	(0.39)	(0.49)	(0.56)	(0.42)
Severn	0.47	0.44	-	0.33	0.45	0.38	0.11
	(0.28)	(0.27)	-	(0.49)	(0.45)	(0.39)	(0.56)

FIRST COMPLETE FREEZING

	Moose	Albany	Severn	York 1	York 2	Churchill 1	Churchill 2
Eastmain	0.55	0.55	0.53	0.49	0.46	0.40	0.56
	(0.30)	(0.27)	(0.39)	(0.39)	(0.57)	(0.37)	(0.39)
Severn	0.46	0.58	-	0.61	0.36	0.42	0.56
	(0.32)	(0.28)	-	(0.45)	(0.49)	(0.37)	(0.48)

FIRST BREAKING

	Moose	Albany	Severn	York 1	York 2	Churchill 1	Churchill 2
Eastmain	0.69	0.69	0.60	0.28	0.56	0.34	0.29
	(0.27)	(0.25)	(0.35)	(0.35)	(0.45)	(0.35)	(0.30)
Severn	0.64	0.57	-	0.57	0.70	0.27	0.41
	(0.28)	(0.27)	-	(0.45)	(0.42)	(0.32)	(0.32)

Note: Definitions of first partial freezing, first complete freezing, first breaking and of York 1, York 2, Churchill 1 and Churchill 2 are given in Moodie and Catchpole (1975).

TABLE 2: *MEANS, STANDARD DEVIATIONS AND EXTREMES OF ICE DATES.*

	FIRST PARTIAL FREEZING				FIRST COMPLETE FREEZING				FIRST BREAKING			
	n*	s*	e*	l*	n	s	e	l	n	s	e	l
Albany	301	8.0	282	331	313	7.7	291	342	128	5.7	106	150
Moose	304	7.5	281	335	312	9.1	290	341	127	6.1	105	145
Eastmain	301	6.6	281	328	319	9.9	290	348	136	6.1	113	161
Severn	291	7.8	270	311	307	11.2	282	338	132	9.6	111	154

* n = normal (1747-1776), s = standard deviation (1747-1776), e = earliest whole period of record, l = latest whole period of record.

Note: 1. Definitions of first partial freezing, etc. are given in Moodie and Catchpole (1975).

2. Dates are given in days after December 31.

the James Bay means. These results indicate that it is practicable to combine the Albany, Moose and Eastmain dates in the calculation of James Bay regional means, but that it is not feasible to combine the dates for all estuaries in the calculation of Hudson Bay regional means.

The James Bay regional means are derived from three records that differ in their terminal dates and continuity. Consequently, annual James Bay means cannot be obtained by averaging three individual values in each year between 1721 and 1921. During that period, for example, are 85 years in which dates of breaking are available from two estuaries, 43 years in which they are available from only one estuary, and eight years in which no dates of breaking are available.

In years having individual dates from all three estuaries, the James Bay mean is obtained by averaging these values. When only two dates are available in a particular year, an estimate of the James Bay mean is obtained by adjusting the two available dates and by averaging the adjusted dates. When only one date exists, it is adjusted and treated as the best estimate of the James Bay mean. These adjustments are the amounts by which the 30-year normals of each freezing and breaking date at the individual estuaries differ from the 30-year normals for James Bay derived by averaging the dates from all three estuaries. These normals are based on the period 1747-1776, a 30-year period in which records from the three estuaries are complete.

The James Bay regional means are illustrated in Figure 5.

Sea Ice in Hudson Strait

A previous report (Catchpole 1980) has discussed the potential climatic value of ship's logs preserved in the Hudson's Bay Company archives. These are logs of ships which engaged in the annual fur trade between London and Hudson Bay. Log records extend from 1751 into the twentieth century, being broken only in the years 1839, 1840 and 1841. In most years, two or more logs are available because several logs were often kept on one ship and because the trade was usually conducted by more than one ship. In this initial use of ships' logs, attention is restricted to the *westward* passage through Hudson Strait. This part of the voyage was selected because of the especially favourable circumstances that it provides for locating the ships precisely. The strait is about 1000 km in length from Cape Digges to

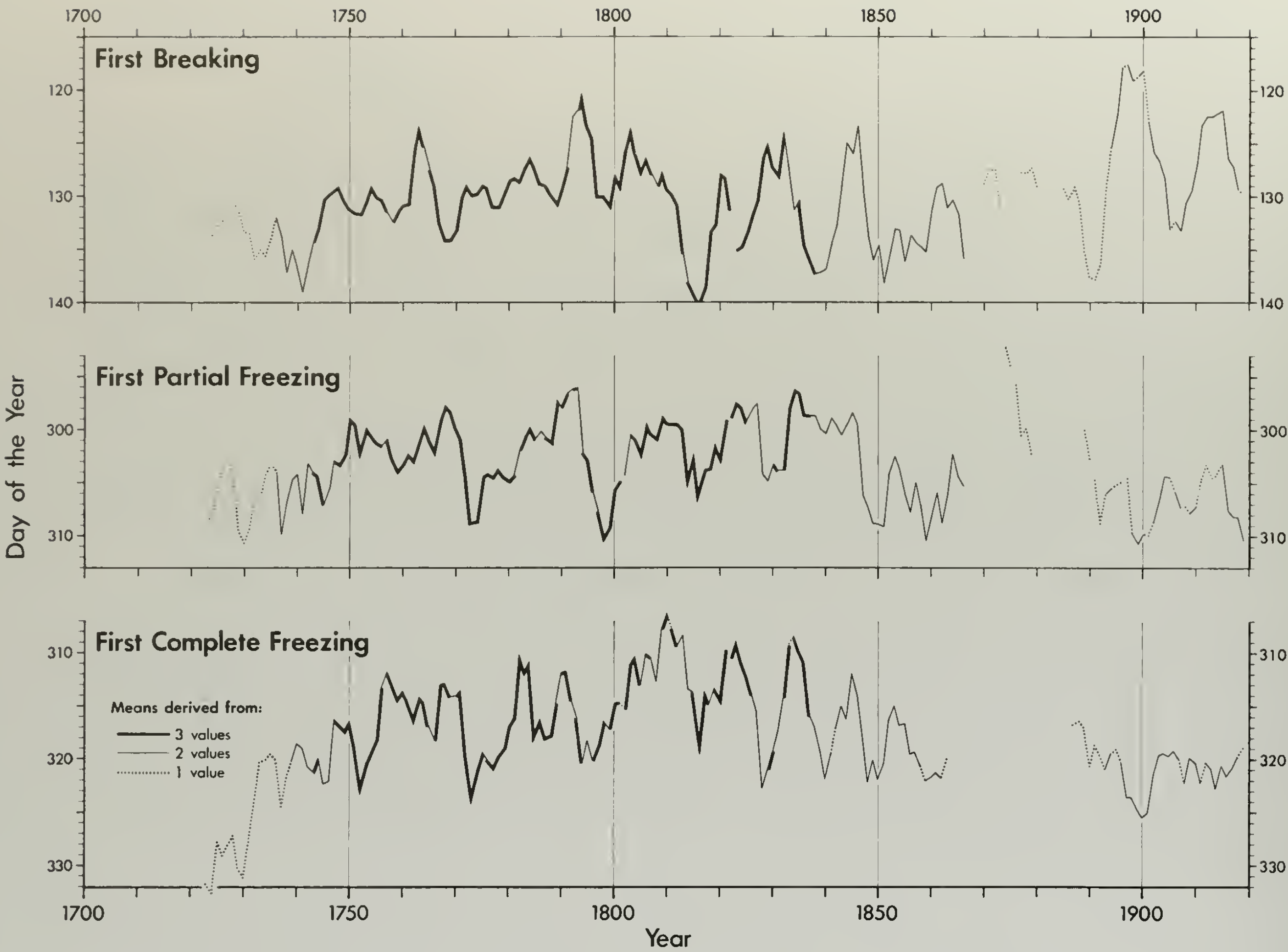

FIGURE 5: *Mean dates of first breaking, first partial freezing and first complete freezing, James Bay region, 1721 to 1921. Dates are given in 5-year running means.*

Resolution Island and is approximately 200 km wide. The Company's ships followed a route that usually permitted sightings upon landmarks (Figure 6), and these sightings were recorded in the logs so that ships's position can often be located fairly accurately. The Company established a routine whereby trading ships were expected to leave the Thames Estuary on May 31. This was not rigidly adhered to, but ships rarely made their departure more than a week prior to or following the established date. This had the effect, not only of imposing a routine on the voyages (which is beneficial in this research), but also of bringing the ships into Hudson Strait in July when sea-ice conditions were severe and posed a hazard to navigation. An impression of the temporal context of the voyages is given in Figure 7. This diagram shows, in each year, the date of embarkation from London, the period spent in westward navigation of Hudson Strait, the interval in Hudson Bay, the period of eastward navigation through the strait and the time of arrival at London.

The logs were written at two-hour intervals with a daily summary. They give routine information on ship's speed, depth of water, wind speed and direction, and weather. A remarks column contains various data including information upon the appearance of ice as well as sailing manoeuvres adopted to avoid ice.

A preliminary scrutiny of the logs indicated that they contain two general types of information that may be used to derive indices of annual sea-ice conditions. The first comprises direct descriptions of the ice - its extent, frequency, movement, etc. The second has an indirect bearing on sea-ice severity since it comprises information on sailing manoeuvres required to negotiate sea ice. The logs are full of references to ships being closed-in, or fast, and to occasions when ships were manoeuvred to avoid ice by tacking, grappling or warping.

The original objective of this research was to develop a content analysis for deriving indices of ice severity from ice descriptions, but this was later modified to interpret sailing information first. The remainder of this section outlines the method used to derive annual indices of sailing manoeuvres, determined by the presence of ice, during westward passages through Hudson Strait. It is assumed that these indices provide indirect estimates of annual sea-ice intensities.

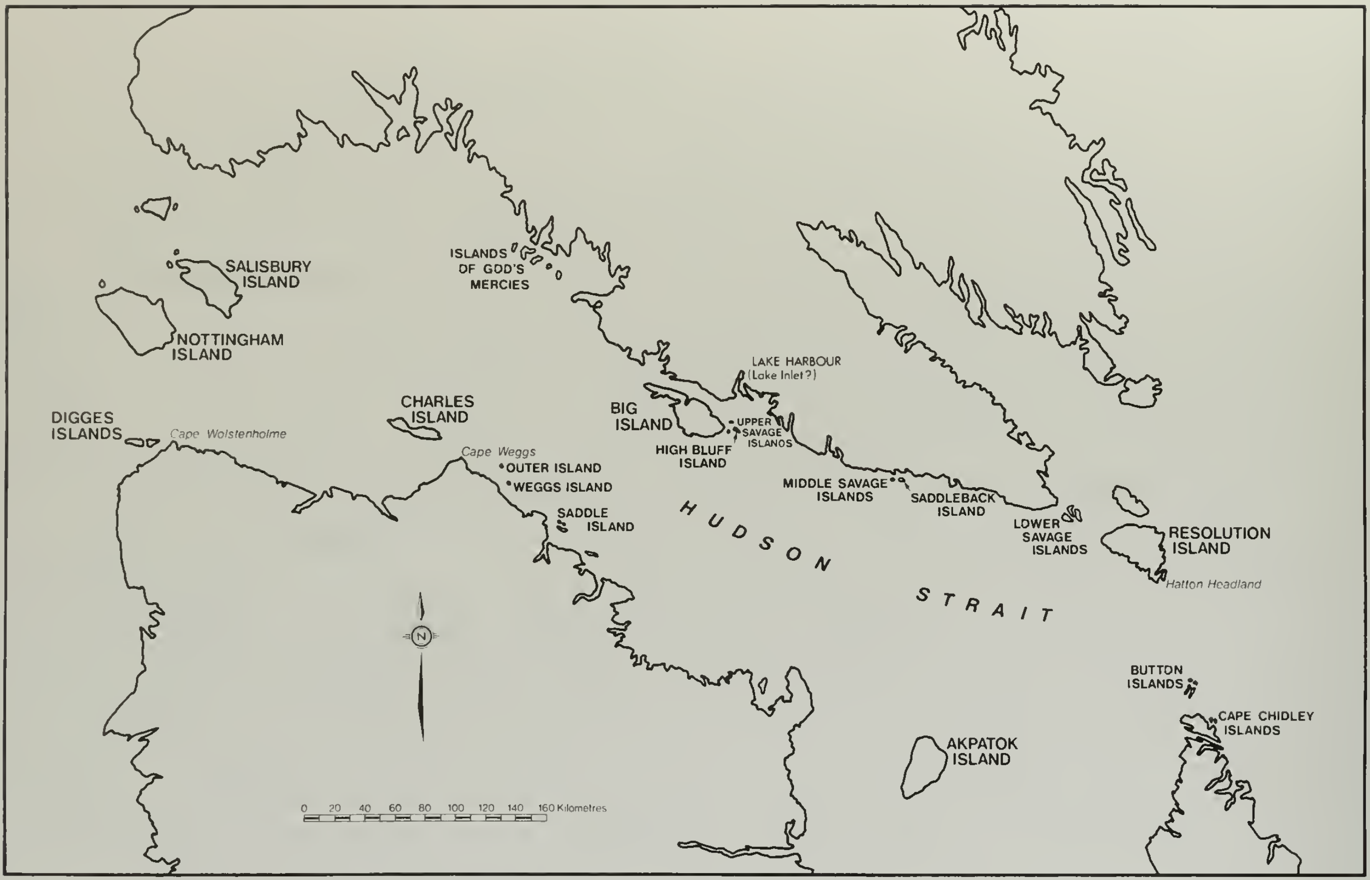

FIGURE 6: *Hudson Strait with place names mentioned in ships' log books.*

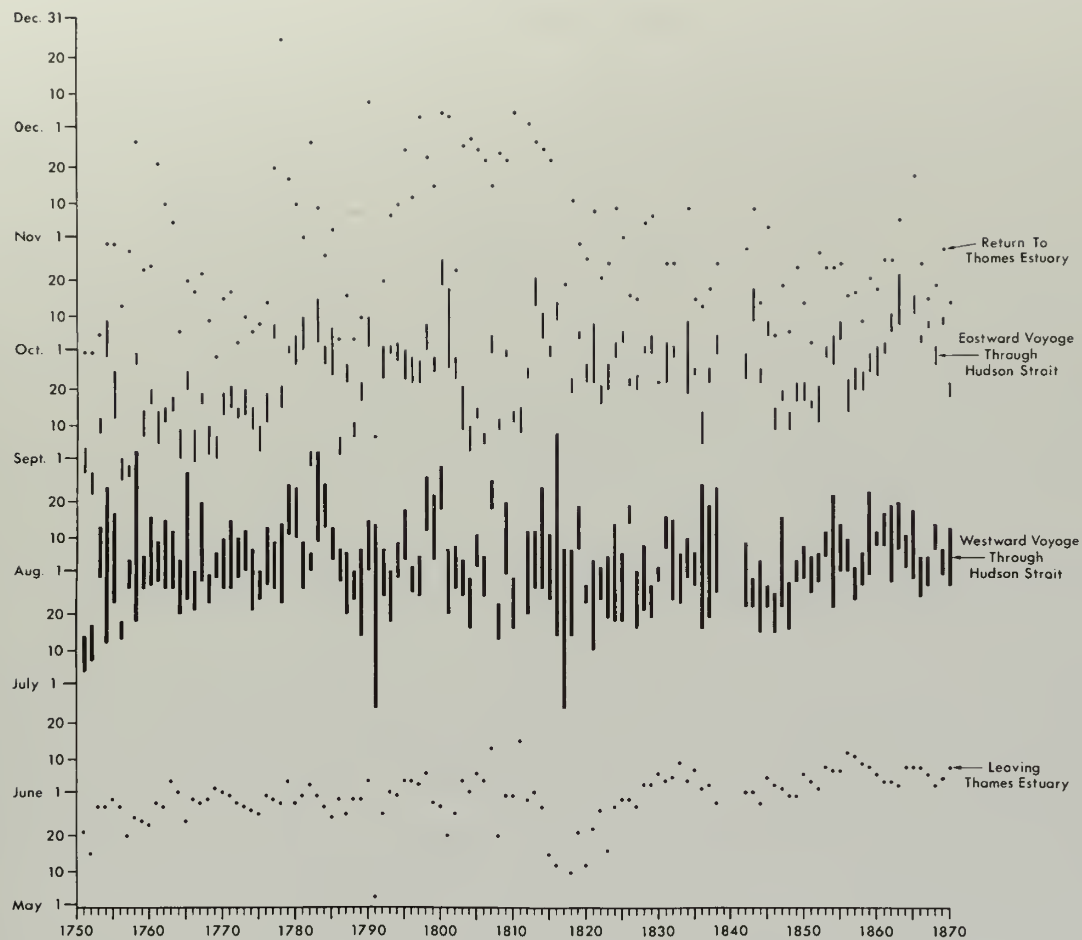

FIGURE 7: *Voyages of Hudson's Bay Company ships between London and the Bay, 1751 to 1870.*

Data Cards

For each year between 1751 and 1870 a data card was prepared and sailing information was recorded on these cards from the logs. Table 3 illustrates the format of the data cards. During westward voyages, the ship was defined as having entered Hudson Strait when Resolution Island was first sighted, and the exit from the strait was indicated by the last sighting of Cape Digges. Daily information was recorded on the cards, for example, names of places visible, distances and bearings of landmarks, references to ice, weather and occasions when people aboard the ship were engaged in trade with the Inuit. Caution was required when recording information on the data cards, since places were sometimes vaguely identified, distances were given in miles or leagues, bearings required correction for magnetic declination and were usually given in the unfamiliar 32-point compass scale (N, N by E, NNE, NE by N, NE, NE by E, ENE, E by N, E, etc.).

Durations of Westward Passages

Durations varied from more than 50 days to less than 6 days. A wide variety of factors, in addition to the severity of sea ice, are potential causes of such variations in duration. Alternative factors include: weather conditions; ship design and performance; skills and experience of captains; and trade with the Inuit. Furthermore, when the role of sea ice is considered in this context, it is necessary to distinguish between the effects of year-to-year changes in ice severity, and the effects of different times of arrival at Resolution Island. The seasonal sea-ice regime determined that passages which commenced early tended to encounter more ice and therefore were of greater duration.

The impact of date of arrival on duration was first studied by correlating the two variables. The Pearson product - moment correlation coefficient was -0.4. This indicates that a weak inverse relationship exists between the two variables. A correlation to actual durations was then obtained using the linear regression relationship:

$$Da = D - b\,(x_i - \bar{x}) \qquad (1)$$

where Da = adjusted duration

D = actual duration

b = -0.38

x_i = date of arrival at Resolution Island in year i

$\bar{x}$ = Mean date of arrival at Resolution Island

TABLE 3: *EXAMPLE OF DATA CARD USED FOR RECORDING SAILING INFORMATION.*

YEAR: 1772 SHIP: King George PIECE NUMBER: 376

OFFICER: J. Fowler

Day	Place Name	Distance	Remarks
July 30	Cape Resolution	NNW1/4W 6 miles	haze, cloud
31	the body of Lower Savage Is.	ENE 6 or 7 leagues	fog
Aug. 1	Is. of Saddle Back	North 10 miles	haze, cloud, rain
2	nearest land S. shore westmost land in sight	E by N 5 miles NNW1/2W 10 leags.	trade
3	the body of Great Savage Is.	ENE 9 miles	tacked, fog
4	North Shore	East 7 or 8 leags.	fog
7	the body of Charles	SWbyW 7 leagues	tacked for ice, fog, haze, gales, cloud
8	E end of Salisbury	N1/2W 9 leagues	hazy
9	SE end of Nottingham	NNE 5 leagues	fog, gales
10	saw Mansfield	SSW to WSW	rain, gales, heavy showers of snow

A second correction for date of commencement of the passage through Hudson Strait involved derivation of the index Dmin. The navigation season was divided into weeks which were numbered sequentially from 1 to 12. Week 1 is June 21-28 (the time of the earliest passage, in 1791) and Week 12 is September 7-13 (the time of the latest passage, in 1811). The total number of passages in each week was enumerated and the minimum duration (Dmin) of the passages in each week was identified. The actual duration (D) in each year was then expressed as a proportion of Dmin for the week in which it occurred. Figure 8 illustrates the temporal variations of actual duration D, and D/Dmin is shown in Figure 9.

The relationships between duration and the quality of the ships and abilities of the ships' captains have not yet been fully considered. There are grounds for anticipating that neither of these relationships had an important bearing on variations in duration. An important characteristic of the voyages is that they were often made by several ships in convoy - including, quite often, a Royal Navy escort. Faster ships were routinely delayed while the convoy reassembled. In these circumstances, skillful navigation by individual captains, or rapid sailing of particular ships, were unlikely to have markedly reduced durations. A correlation analysis of the impact of years of experience of captains upon duration has supported this assumption. This was conducted by correlating the mean duration of the voyages undertaken by 24 different captains with the number of voyages undertaken by each captain. This yielded a correlation coefficient of only -0.17. Furthermore, a regression analysis indicated that the durations of voyages under one captain did not decrease as the number of voyages undertaken by that captain increased.

Documentation in the logs of weather conditions and trading activities is sufficiently detailed to permit identification of the days on which passage through Hudson Strait was primarily delayed by these factors. Interpretation of this information, and of information pertaining to the effects of sea ice in delaying passages, are presented in the following section.

Analysis of Sailing Manoeuvres

This analysis commenced with the identification of the days in each year when the following conditions or activities were described in the logs: ship fast in ice; beset by ice; grappling or warping with ice; tacking to avoid ice; adverse weather conditions; and trading with the Inuit. Figures 10 and 11 depict the temporal distributions of occasions

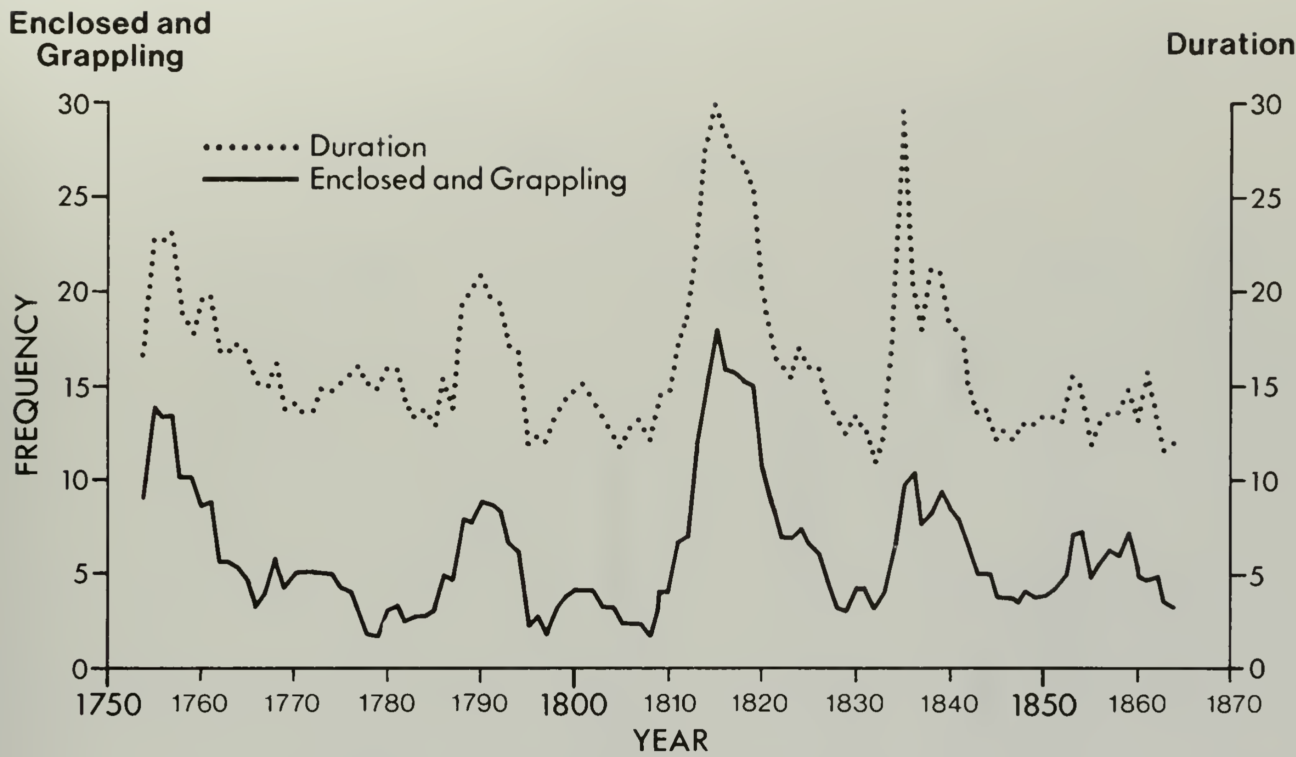

FIGURE 8: *Westward voyages of Hudson's Bay Company ships through Hudson Strait. The annual durations of these voyages are compared with the frequencies with which the ships became enclosed in ice and grappled with ice.*

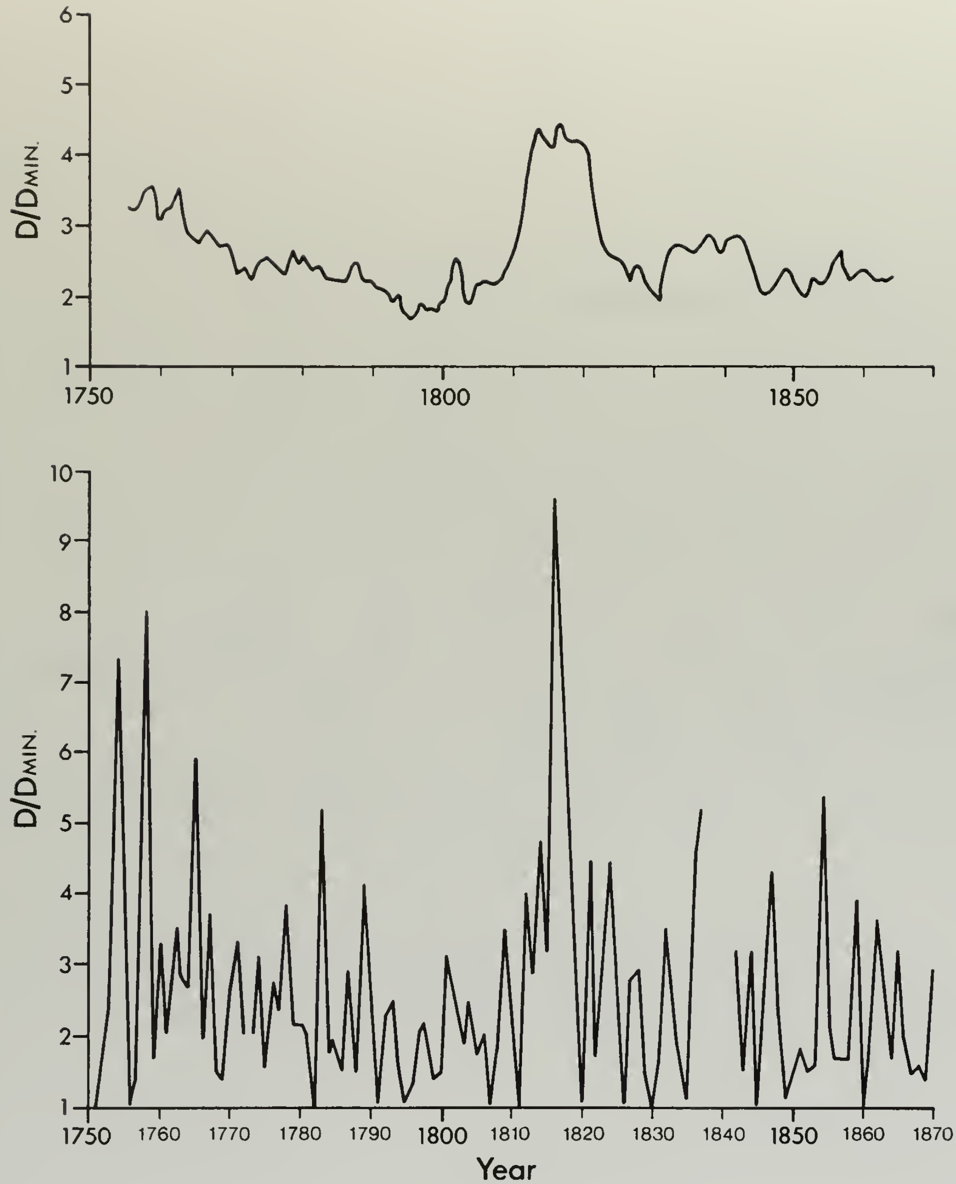

FIGURE 9: *Annual variations in the index D/Dmin. The upper graph contains 5-year running means and the lower graph contains actual values.*

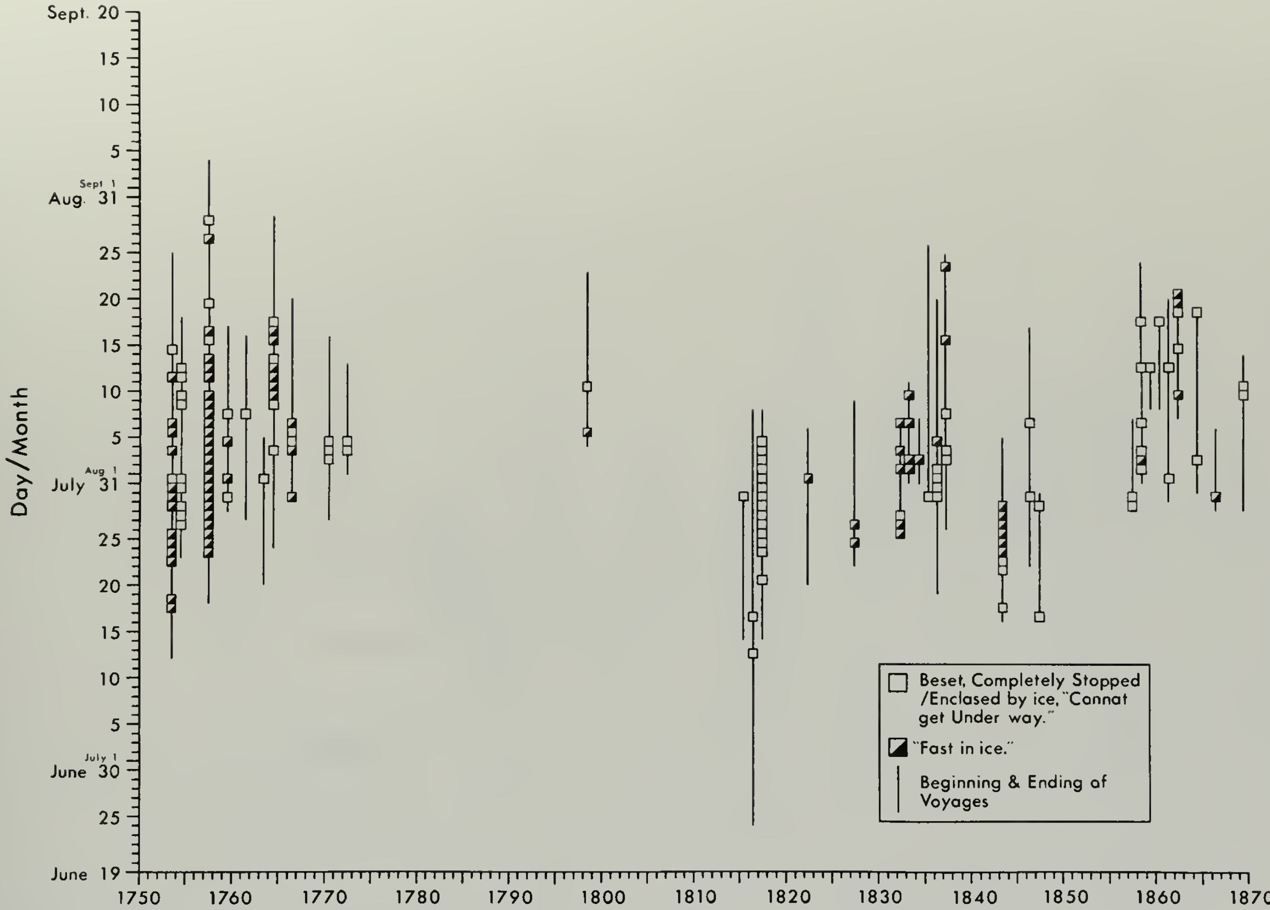

FIGURE 10: *Occasions when ships were beset by, or fast in, ice during westward voyages through Hudson Strait between 1750 and 1870. The vertical line shows the duration of the westward voyage through the strait in each year when the ships were beset by, or fast in, ice.*

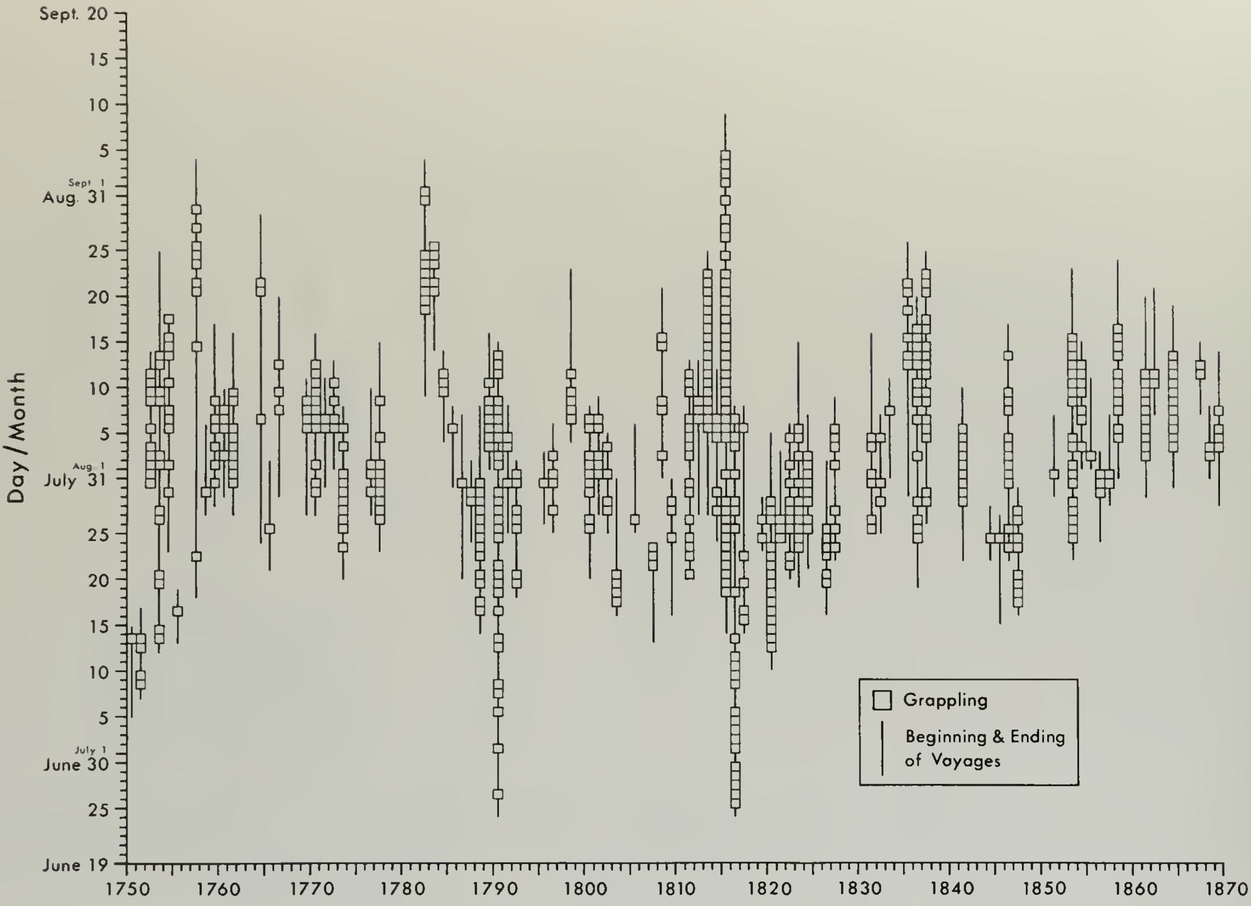

FIGURE 11: *Occasions when ships grappled with ice during westward voyages through Hudson Strait between 1750 and 1870.*

when the ships were beset by and fast in ice, and grappled with ice, respectively.

The sailing manoeuvres responsible for delaying progress during prolonged westward passages were studied by correlating actual durations (D) with the following parameters:

(1) number of days T on which the ship tacked to avoid ice during the westward passage from Resolution Island to Cape Digges ($r = +0.09$);

(2) number of days G on which grappling or warping with ice occurred ($r = +0.84$);

(3) number of days E on which ship was enclosed in ice, fast or beset ($r = +0.50$).

Both G and E are significantly correlated with duration. The correlation coefficient between D and the sum of G and E (G + E) is +0.92. This indicates that manoeuvres involving contact with the ice significantly prolonged the duration of the westward passage. It implies that the basic cause of annual fluctuations in the duration of westward passages through Hudson Strait was the frequency with which the ship grappled with or became fast in ice. It also implies that annual fluctuations in D provide an indirect indication of yearly changes in the amount of ice. Figure 8 illustrates the relationship between D and (E + G).

The occurrence of tacking does not significantly prolong D. Presumably this is because a ship resorted to tacking in the presence of ice which was not of sufficient amount to prevent it making headway. Further, the high correlation between D and (E + G) indicates that factors unrelated to ice play a minor role in determining annual fluctuations in D. Several such factors are under investigation including adverse weather conditions (fog, strong winds, snowfall), as well as delaying activities including trading with the Inuit and waiting for consorts. Preliminary investigations suggest that none of these factors, individually, was a significant determinant of D.

DATES OF FIRST SNOWFALL AND FIRST FROST

This study has close affinities with that of dates of freezing and breaking. Like the latter it involves the use of information in the Hudson's Bay Company post journals, and its objective is to derive phenological* indices of climatic change. European and Far Eastern research has shown that historical documents containing evidence of climatic change can be most effectively used in two ways:

(1) identification of rare and extreme occurrences such as droughts, severe winters, floods or storms;

(2) study of phenological indicators such as dates of first snow in fall, river breaking and freezing, first migration of birds or ripening of fruit.

The goal of this research is to obtain dates of first snowfall and frost from the post journals. Snowfall and frost studies are being conducted simultaneously using the same general methods. At the outset, these were resolved into the following discrete stages:

(1) transcription of journal references to snowfall and frost;

(2) development of general methods for analyzing transcribed references, using information from Moose Factory and Fort Albany post journals;

(3) testing the results and refining the methods;

(4) applying the methods to post journals from a network of trading posts.

The procedures which were eventually adopted conformed closely with this scheme, although minor modifications were adopted. The first three stages are now complete.

Transcription of References to Snowfall and Frost

This work was undertaken by an experienced assistant who had previously transcribed all information used in the study of first freezing and breaking. The objective of the transcription was to extract from the journals, in each year, information that would serve to identify the date of first snowfall and first frost. The assistant was instructed to read each daily entry made between July 1 and October 31, and transcribe *verbatim* all daily references to snow and frost in that period. For each year, the assistant was permitted to terminate the transcription before October 31 if it became clear to him that the first

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* Ed. Note: Phenology is the study of relations between climate and recurring natural phenomena.

snowfall and first frost had already occurred. In this way, over 200 foolscap pages of daily transcriptions were prepared.

<u>Analysis of Transcriptions from Moose Factory and Fort Albany</u>

The transcribed information comprised a large amount of heterogeneous descriptions of snow and frost phenomena. Information of this nature had previously been interpreted, in the study of dates of freezing and breaking of water bodies, by the development of a method of content analysis. Previous experience prompted the assumption that a similar method of content analysis would be required to extract dates of first snowfall and first frost from the transcribed information. This endeavour met with less success in the present study than in the previous ones. The following account describes procedures adopted to develop a suitable content analysis of first snow fall and first frost data. Later, utility of the method of content analysis in these contexts will be discussed.

One research assistant spent a year seeking to develop methods of content analysis for interpretation of snowfall and frost information. This investigation commenced with extraction, from all transcribed information, of two random samples of daily comments - one pertaining to frost descriptions, the other to snowfall descriptions. Each random sample was scrutinized, and classifications of types of reference to snowfall and frost were developed. The reason for these classifications was to identify types of descriptions of snowfall and frost referring to specific meteorological phenomena and which occur frequently in the post journals. Classes of description which meet these criteria would, it was expected, provide a basis for deriving homogeneous, continuous records of dates of first snowfall and first frost. Initial efforts yielded many classes which were unsatisfactory because they failed to meet the criteria of meteorological specificity and high frequency of occurrence. The classifications were refined to six categories of snow descriptions (snow lying, heavy snowfall, light snowfall, snow with rain, snow with hail, vague references to snow) and four categories of frost description (comments diagnostic of radiation frost, advection frost, recorded sub-freezing temperatures, vague references to frost).

These classifications of types of reference to first frost and snow are much simpler than the classifications of references to first freezing and first breaking of water bodies developed previously. Several factors have contributed to this contrast. The processes of freezing and breaking of water bodies are protracted, intermittent processes in which several days or weeks elapse between the first appearance of ice or manifestation of breaking, and complete freezing or clearing of ice. The initial objective of the freezing and breaking study was to identify dates of major stages in these processes and the assistant was, accordingly, instructed to transcribe all references bearing upon the various stages. The processes of development of the winter snowpack, and of freezing conditions in the air or in the ground are also prolonged, intermittent processes covering periods of days or weeks. However, at the outset of the snow and frost studies, a limited goal was set of identifying only the initiation of these processes. Therefore, the assistant was instructed to transcribe only data bearing upon their initiation. Hence transcriptions of first snow and first frost descriptions embraced a narrower range of information than the transcription of the first freezing and first breaking descriptions.

A second factor contributing to the comparative simplicity of the categories of frost and snow descriptions relates to spatial variations of these phenomena. Within estuaries of rivers draining into Hudson Bay, there are substantial spatial variations in times of river freezing and breaking. These variations are determined by hydrological and topographical conditions, and tend to follow similar patterns from year to year. Therefore, an important component of the classification of freezing and breaking descriptions involved the places to which these descriptions referred. This spatial component has not entered into the classification of first snowfall and frost descriptions, because significant, regular, local variations in these elements are not apparent in the post journals.

Testing the Quality of the Dates of First Snowfall and Frost Derived at Moose Factory and Fort Albany

The principle of spatial homogeneity testing has been applied in this context. It is founded on the assumption that locations within a particular climatic region tend to experience similar climatic changes. The closer such points are together, and the greater the physical similarity between them, the greater will be the parallelism between climatic changes that they experience. In the study of dates of freezing and breaking this test was applied to dates derived at Moose Factory and Fort Albany. A high degree of homogeneity was observed between the freezing and breaking dates for these posts. This was taken as evidence that the actual dates of these events in the two estuaries are similar and that the dates derived from the post journals are relatively accurate. Similar homogeneity tests were applied in the present study to the following sequence of dates:

(1) date of first snowfall where this is defined as the first reference to snow each year, irrespective of the class of information contained in that reference;
(2) date of first frost, defined in the same general manner as first snowfall.

Annual dates of first snowfall and first frost at Moose Factory and Fort Albany are shown in Figures 12 and 13, respectively. These dates are expressed in days after July 31, and are corrected for both the Gregorian calendar reform and leap years. In the first stage of homogeneity testing, Pearson's product - moment correlation coefficients between dates derived at Moose Factory and Fort Albany were calculated both for the whole period and for 15-year intervals within that period. The results derived from the snowfall dates are shown in Table 4, and indicate a lack of homogeneity between the two estuaries ($r = +0.32$ in the period 1732-1866). Coefficients derived in the 15-year time intervals demonstrate an erratic variation in the relationships between the two estuaries, with occasions of very close relationships ($r = +0.90$ in the periods 1792-1801 and 1822-1836) alternating with periods when dates at the two estuaries are unrelated. Figures 12 and 13, and Table 4 show that close parallels exist between the trends at the two estuaries in some periods, but at other times considerable discrepancies exist.

The results of this homogeneity test are not decisive. The overall relationship indicates that Moose Factory and Fort Albany are inhomogeneous with regard to dates of first snowfall and frost. However, for brief periods, the two estuaries are much alike. The causes of this inhomogeneity are under investigation and three alternative explanations are being considered:

(1) that the post journals are incapable of yielding valid dates of first snowfall and first frost because their authors did not write about these phenomena in sufficient detail;

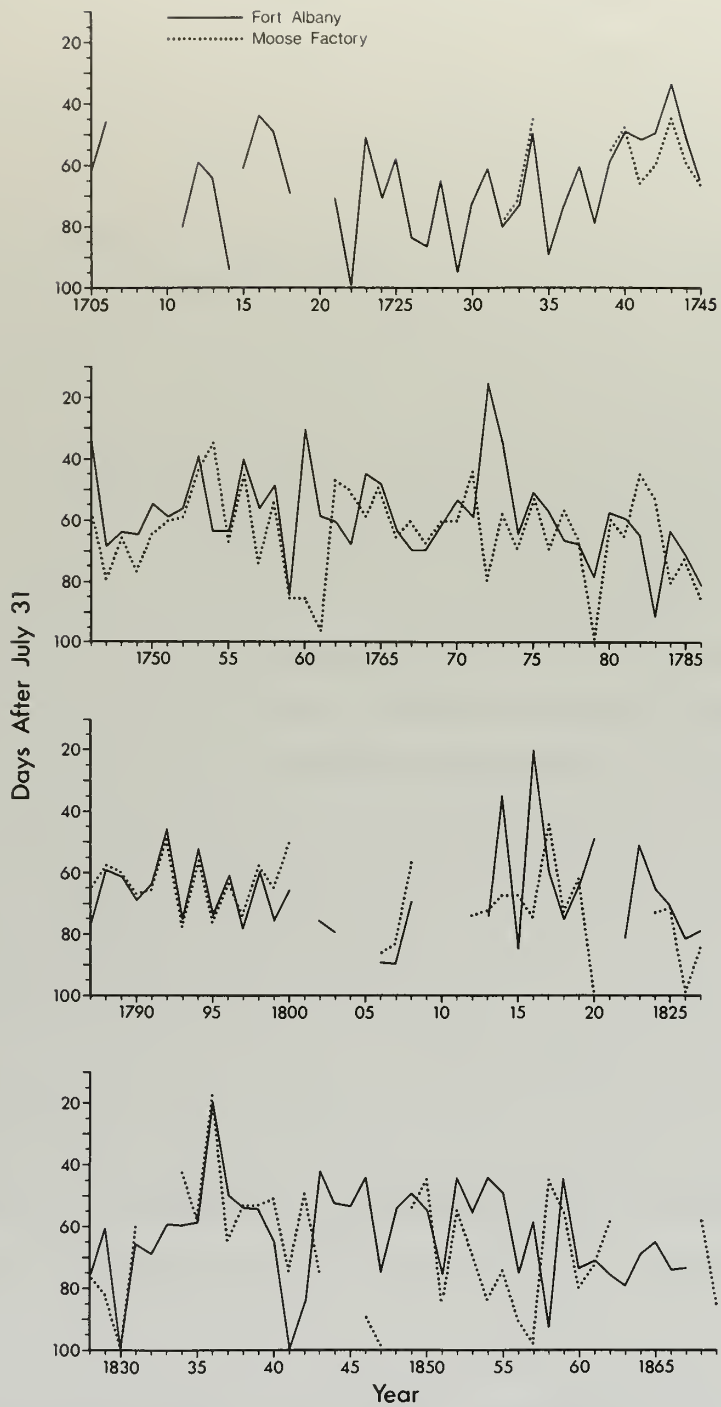

FIGURE 12: *Date of first snowfall after July 31, Moose Factory and Fort Albany, 1705 to 1869.*

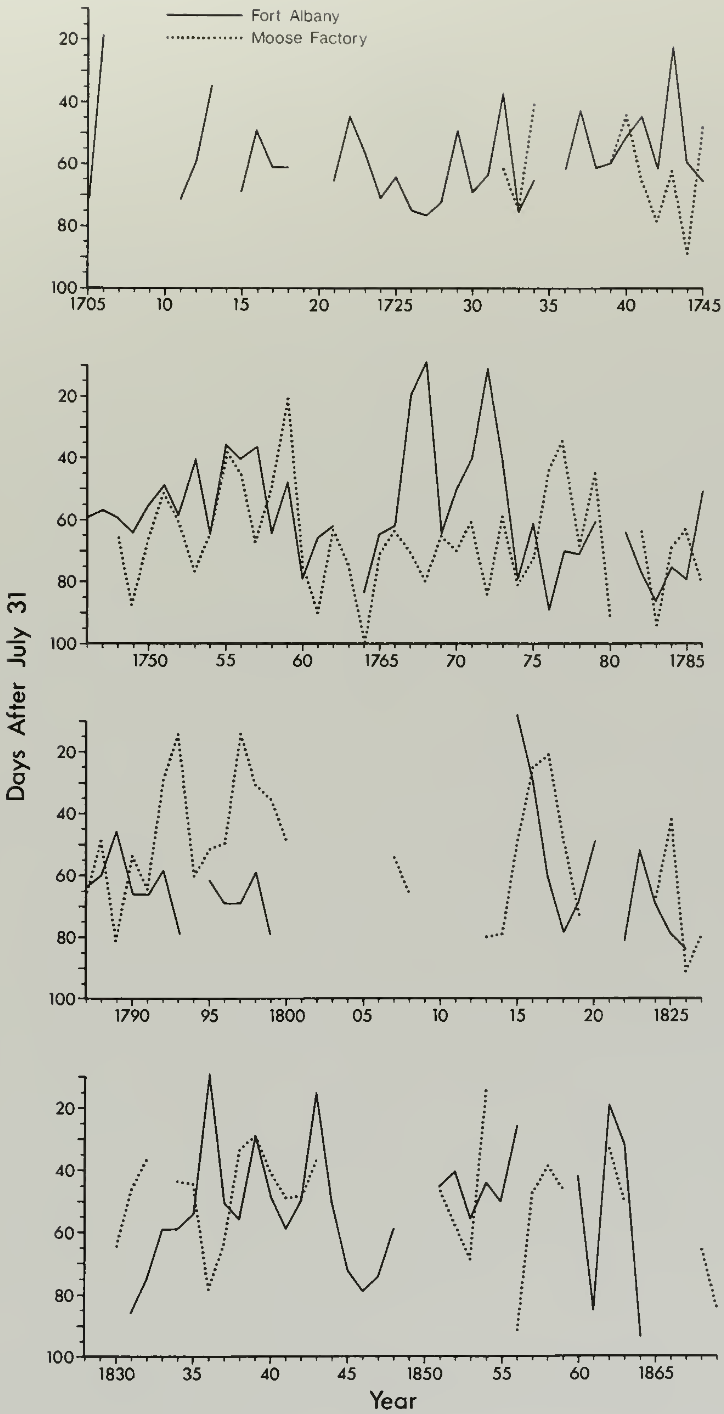

FIGURE 13: *Date of first frost after July 31, Moose Factory and Fort Albany, 1705 to 1869.*

TABLE 4: *CORRELATION COEFFICIENTS BETWEEN DATES OF FIRST SNOWFALL AT MOOSE FACTORY AND FORT ALBANY.*

PERIOD	NUMBERS OF PAIRS OF DATES	CORRELATION COEFFICIENT
1732-1866	111	+0.32
1732-1746	12	+0.60
1747-1761	15	+0.35
1762-1776	15	-0.40
1777-1791	15	+0.20
1792-1801	10	+0.90
1807-1821	10	-0.02
1822-1836	11	+0.90
1837-1851	12	+0.16
1852-1866	12	-0.25

(2) that the post journals are able to yield valid dates, but that discrepancies between tabulated dates at Moose and Albany are caused by errors in transcriptions of references to snow and frost from the primary sources;

(3) that post journals are able to yield valid dates and that the discrepancies between the tabulated dates at Moose and Albany have meteorological causes.

Accuracy of Transcriptions

The accuracy of the original transcribed information was checked by comparing the transcriptions directly with the primary sources. This confirmed the accuracy of the original transcription. A second confirmation of accuracy was obtained by conducting a reliability test in which the dates of first snowfall at York Factory derived in this study were compared directly with similar dates derived by the second author for the same period at York Factory using the same sources (see page 82). Ball's dates were derived from the post journals using the method described later in this report. Identical dates of first snowfall at York Factory were derived by the two studies on 106 out of 139 years. Discrepancies in the remaining 33 years are under investigation: preliminary results indicate that several were caused by simple errors of transcription or coding.

The confirmation of the accuracy of the transcription implies that inhomogeneity between dates of first snow and frost derived at Moose Factory and Fort Albany is attributable to the first or third causes listed above. Thus, the possibility arises that the dates derived from the post journals are accurate and that the differences in dates between Moose and Albany have real physical causes. Modern meteorological records are not available from the estuaries of Moose and Albany Rivers. Therefore, a direct investigation of this question cannot be undertaken. An effort has been made to study the matter indirectly by comparing homogeneity between Moose and Albany dates with the homogeneity among similar dates observed at pairs of modern stations located in southern Manitoba.

Homogeneity in Modern Observations of First Frost and First Snowfall

This study of dates of first frost and first snow observed in southern Manitoba stations cannot confirm the validity of the historical dates derived at Moose and Albany. It is designed to show whether the degree of homogeneity between the historical dates is consistent with the homogeneity between pairs of modern stations near to each other.

From the Manitoba network, four stations were selected on the basis of their relative proximity and longevity: Brandon, Minnedosa, Morden and Winnipeg for the study of first snowfall; and Brandon, Morden, Pierson and Winnipeg for the study of the first frost. The homogenity between the dates of first snowfall observed at the four Manitoba stations was tested using the product-moment correlation coefficient. This generated values ranging from +0.16 to +0.46, indicating that the modern data are no more closely related than are the historical dates derived at Moose and Albany. A similar procedure applied to the first frost dates generated correlation coefficients ranging between 0.25 and 0.68. These values considerably exceed the correlation coefficient between historical dates of first frost derived at Moose and Albany.

ESTABLISHMENT OF CLIMATOLOGICAL DATA BASE FROM YORK FACTORY AND CHURCHILL FACTORY POST JOURNALS

This study is a preliminary phase of the full exploitation of the extensive historical climatological information to be found in the Hudson's Bay Company records. Eventually, it is hoped that all the information contained in these records will be stored in a computer and made available for detailed analysis of the weather patterns of northern North America over the last 250 years. The initial work, briefly outlined here, involves establishment of a system, devised at the University of Winnipeg, for transcribing and coding all references to weather from various types of journals maintained by Hudson's Bay Company employees into a format that allows for easy computer storage and retrieval.

Post Journals Consulted, their Durations and Authors

The York Factory journal commenced in September 1714 (New Calendar) and continued with interruptions to 1913. The most complete portion of this span occurs between 1714 and 1802, during which only two brief gaps occur. The period from September 1739 to August 1740 is missing because of the loss of the records packet when a ship sank. In August 1782 the Bayside forts were attacked by the French, and a gap extends from that time until September 1783 when the Hudson's Bay Company recommenced business.

The post journals were recorded from late August or early September for a complete year. This was the date on which the annual supply ships arrived from England and was the date of any changes in command at the various factories. The meteorological journals, wherein actual instrumental measurements are recorded, also run from approximately September 1 to August 30.

System for Transcribing and Coding

The objective of the system of transcription was to extract all relevant information in a manner that would facilitate coding of this information for computer storage and analysis. The York Factory journal was transcribed first and in two stages. In the initial stage, all references to weather and weather-related phenomena were listed chronologically and verbatim. This transcription was conducted entirely by the second author. Approximately one year of archival research was required. Following the completion of this stage in the transcription of the York Factory journals, it was assumed that the resultant chronological list of weather descriptions contained a comprehensive sample of types of references to weather and environment that occur in the Hudson's Bay Company post journals.

To confirm the assumption that a comprehensive list of weather types had been achieved, a similar transcription was carried out on journals for Cumberland House. These journal were selected because they are from the earliest *inland* post, which was established in 1794. A high degree of correlation was found between the terminologies used in the coastal post journals and those used in Cumberland House journals. This is probably because usually men who had maintained the journals at York Factory or Churchill were transferred to Cumberland House. The only differences were found in the use of terms specifically applicable to the proximity of Hudson Bay. For example, references to Sea Roak or Sea Smoke would obviously not be found in the Cumberland House journals. There were no weather types found that were peculiar to Cumberland House.

The second stage in the transcription of the York journals involved identification of types of description and the subsequent classification of these using the system contained in Table 5. The Churchill Factory post journal was then coded directly using this classification without the intermediate transcription of chronological notes that had been applied to the York journals. Coding of the transcribed notes from the York journals, and direct coding of the Churchill information took approximately 2.5 years.

TABLE 5: *CLASSIFICATION OF WEATHER DESCRIPTIONS IN POST JOURNALS.*

ELEMENT	CLASS
Precipitation - Rain (27-29)*	Rain(101)**, inclined to rain(102), light(103), drizzle(104), occasional(105), showers(106), squalls(107), heavy(108), continuous(109), most of day(110), part of day(111), with snow(112), at night(113), with fog(114).
Precipitation - Snow (27-29)	Snow(201), inclined to snow(202), light (203), small(204), occasional(205), showers(206), squalls(207), heavy(208), continuous(209), most of day(210), part of day(211), with rain(212), with hail(213), at night(214), freezing rain(215), with hail and rain(217).
Other Precipitation (27-29)	Sleet(301), rime(302), thick rime(303), hail(304), flying showers(305), fog(306), thick fog(307), haze(308), fog in morning(309), mizzling(310), dew(311).
Wind - Direction (23)	N(01), NNE(03), NE(05), ENE(07), E(09), ESE(11), SE(13), SSE(15), S(17), SSW(19), SW(21), WSW(23), W(25), WNW(27), NW(29), NNW(31), Variable (33).
Wind - Strength (20-21)	Little(01), small(02), gentle(03), light(04), fresh(05), brisk(06), stiff(07), hard(08), heavy(09), strong(10), very strong(11), decreasing (13), moderate(14), storm(15).
Other Wind (22)	Calm(1), variable(2), wind(3), breeze(4), gale(5), squalls(6), blowing(7), almost calm(8).
Thermal - Temperature Reading (13-17)	Value recorded positive(1), negative(2).
Thermal - Relative Warmth (32-33)	Very hot(1), hot(2), very warm(3), warm(4), warmer than yesterday(6), extremely hot(7), cool(8), sharp(9), very sharp(10), cold(11), very cold(12), freezing(13), extremely cold(14), colder than yesterday(15), warm for season(16), cold for season(17), raw(18).

TABLE 5: (Cont'd)

ELEMENT	CLASS
Thermal - Thaw (35)	Thaw(1), thaw at noon(2), thaw all day(3), thaw in lee(4), thaw in sun(5), thaw out of wind(6).
Thermal - Frost (36)	Frost(1), hard frost(2), hoar frost(3), froze hard at night(4), frost at night(5).
Cloud (30)	Clear(1), cloudy(2), overcast(3), flying cloud(4), part clear(5), part cloudy(6), part clear part cloudy(7).
Thunder (31)	Thunder(1), lightning(2), thunder and lightning(3).
Drifting Snow (37)	Drift(1), low drift(2), heavy drift(3).
General (34)	Pleasant(1), fine(2), mild(3), moderate(4), stormy(5), heavy, close, thick, ugly(6), fair(7), sultry(8), variable(9).

* Numbers in parenthesis beside each element indicate columns on computer card where element is coded.

** Numbers in parenthesis beside each class indicate the code used to identify that class on computer cards.

The coded information was then transferred to computer cards and approximately 6 million bits of information were thus key-punched. Both the transcribed notes and the computer cards were systematically edited in order to identify errors of transcription or key-punching.

Analysis of Phenological Indicators

Analysis of descriptive climatic information should proceed in two stages. Primary analysis involves the numerical investigation of individual weather elements. Secondary analysis involves the synthesis of many weather elements in the study of synoptic weather systems. Most work to date involves primary analysis.

In general, the primary analysis of descriptive climatic information seeks to identify two types of parameters, namely, phenological indicators, and measures of frequencies or intensities of occurrence. Phenological indicators that have been analyzed to date are discussed below.

Date of First Rain in Summer

Figure 14 charts data on the first mention of rain after March 1 for each year. Those years in which rain occurred prior to that date are considered as exceptional cases. They will be considered in another portion of the study.

Date of First Snowfall in Winter

The first snowfall is defined as the first mention of snow after August 1, without distinction between snow flurries or a continuous or heavy fall (Figure 15).

Date of First Thaw in Spring

The base date for this analysis (Figure 16) was also established as March 1. Records prior to that date will also be shown in a later study. As can be seen from Table 5, there are six classes of thaw with each distinguishing between thawing due to above-freezing ambient air temperatures (thaw in the shade) and thawing due to a positive net radiation balance (thaw in sun). There was no attempt to distinguish between these types in Figure 16.

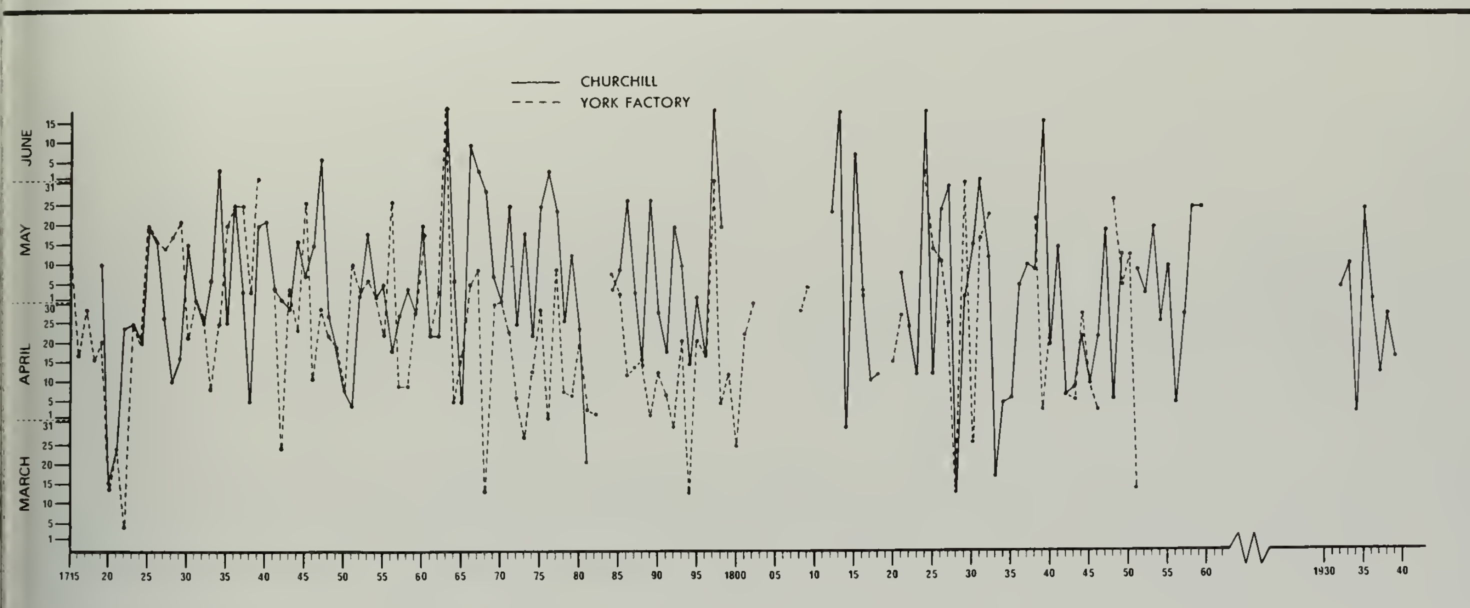

FIGURE 14: *First day of rain after March 1 at York Factory and Churchill (1715-1940).*

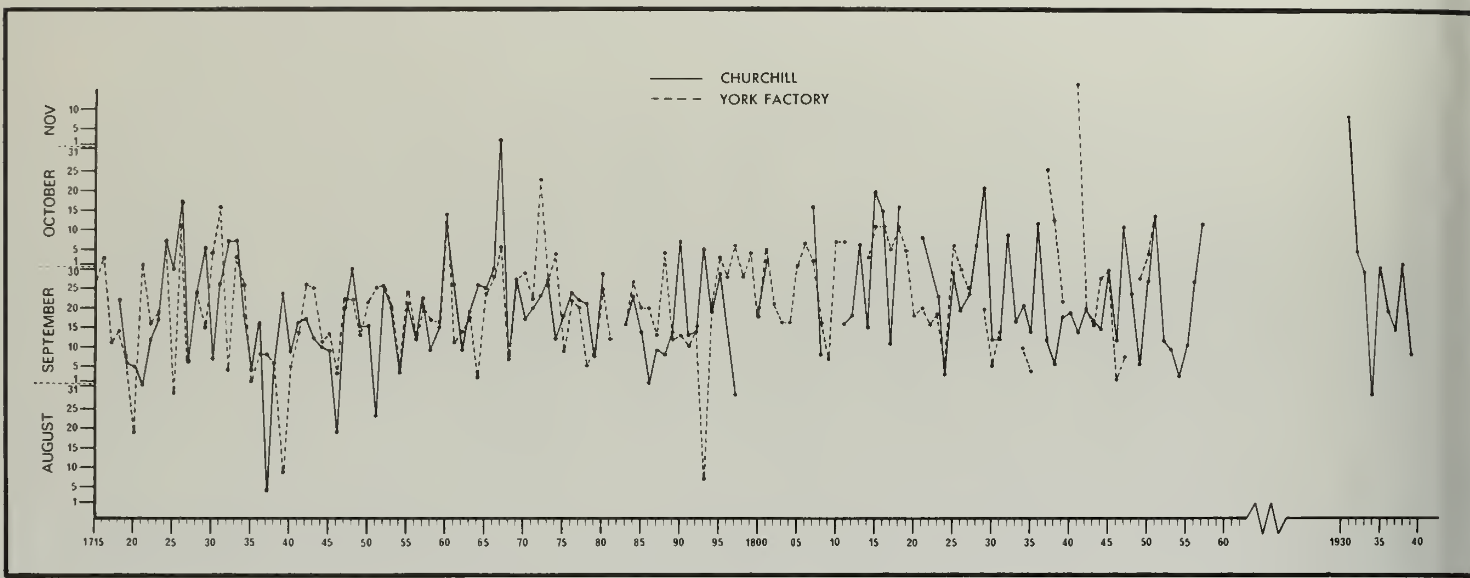

FIGURE 15: *First day of snow after August 1 at York Factory and Churchill (1715-1940).*

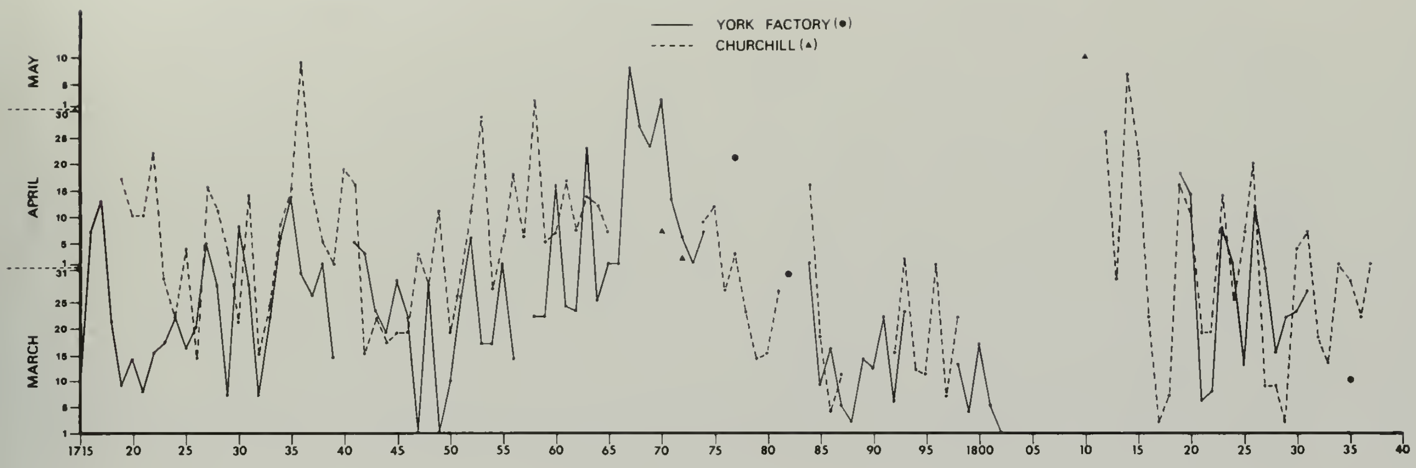

FIGURE 16: *First day of thaw after March 1 at York Factory and Churchill (1715-1840).*

Date of First Day of Frost in Fall

Unfortunately, this is the most incomplete of the graphs (Figure 17) presented, nonetheless trends appear to be evident. The computer was programmed to select the first recorded frost after August 1, but the earliest noted frost is September 1. Interpretation of these data is confused by difficulties encountered in the definition of frost.

The problem of identifying frost stems from lack of clear distinction between visible frost and the use of the term frost to merely indicate a relative thermal cooling. In the classification system, frost is placed in two categories, the first under the element of "other precipitation" (Table 5), where it is recorded as rime or thick rime. The second under the element "frost", includes degrees of frost, but also has a category labelled "hoar frost". For the most part, the term rime (also recorded as roak or sea roak) was used to indicate the type of ice that would occur from ice fog drifting in from open water in Hudson Bay. It is important to note that the occurrence of rime is usually associated with an easterly wind. For this reason, rime was classified as a form of advected precipitation, and therefore distinguished from frost occurring due to temperatures falling below the freezing point.

A study will be carried out to further distinguish among these various forms of frost and to associate them with other climatic variables.

Date of First Night Frost in Fall

Unlike the preceding graph, the record of night frost (Figure 18) is restricted to only two categories, namely, "frost hard at night", or "frost at night". Again there is the difficulty of distinguishing hoar frost, or condensed frozen water droplets, from an actual drop in the ambient air temperature below the freezing point. For the time being, it has been assumed that, in both cases, the temperature must fall below the freezing level. However, observers apparently distinguished between precipitated frost and a drop in temperature that was manifested by thin layers of ice on water surfaces in the vicinity.

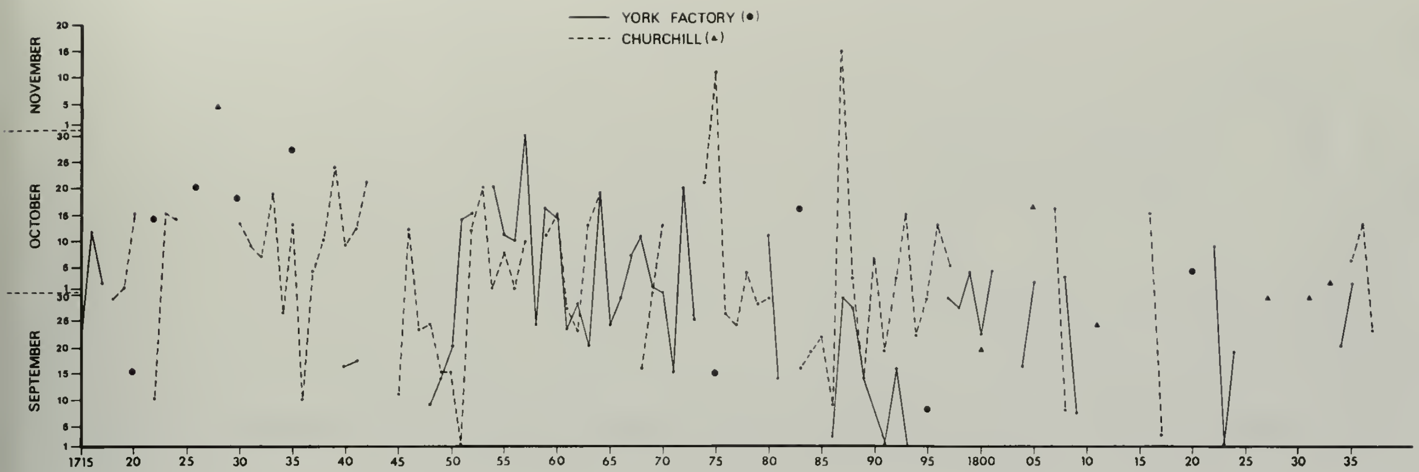

FIGURE 17: *First day of frost after August 1 at York Factory and Churchill (1715-1840).*

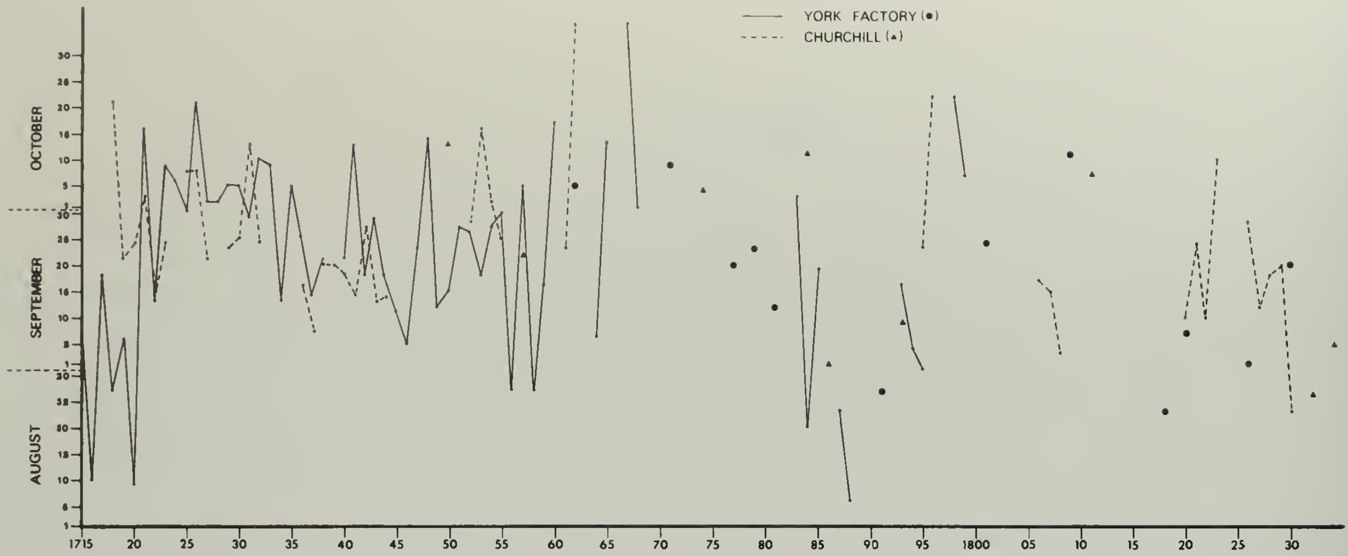

FIGURE 18: *First record of night frost after August 1 at York Factory and Churchill (1715-1840).*

Date of First Thunder in Summer

A confusing aspect of this phenological indicator (Figure 19) lies in the need for observers to distinguish between thunder and other noises. The sound of ice cracking in the Bay or on the river may occasionally have been mistaken for thunder, particularly if it was a distant sound. The problem is further complicated by the fact that the first thunder would tend to be coincident with the breaking up of the ice, either because of warmer temperatures or because of wind shifts that cause ice to shift. Another possibility is that the sound of ships' cannon, which were used as signalling devices, could be mistaken for a clap of thunder. This is of less concern, because it is possible to check on the arrival or departure of ships around the time of recorded thunder.

Finally the assumption was made that lightning and thunder always occur together, even though the observer sometimes only notes one or the other. The term thunder was chosen as the title of Figure 19 because it is the more frequently used term. Presumably, this is attributable to the fact that the ears are "omni-directional", while eyes have a restricted field.

The significance of this variable is the association of cumulonimbus clouds with the influx of warm, moist, southerly air. An early migration of the polar front would possibly result in sufficient instability to allow formation of cumulonimbus clouds. It is interesting to speculate on the height of the tropopause* and associated upper air winds during these events, however this will be deferred until the secondary analysis.

Date of First Sighting of Geese in Spring

This variable (Figure 20) is included as a classic example of phenological information, namely the part played by climate in annually recurring nature phenomena. It is anticipated that changes in the date of first arrival of geese in spring might serve as an indicator of climatic change. The hypothesis derives from studies indicating that the birds migrate when they have a tail wind to assist their movement. As a preliminary test, the graph includes a

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* Ed. Note: The boundary region in the atmosphere that separates the stratosphere from the troposphere.

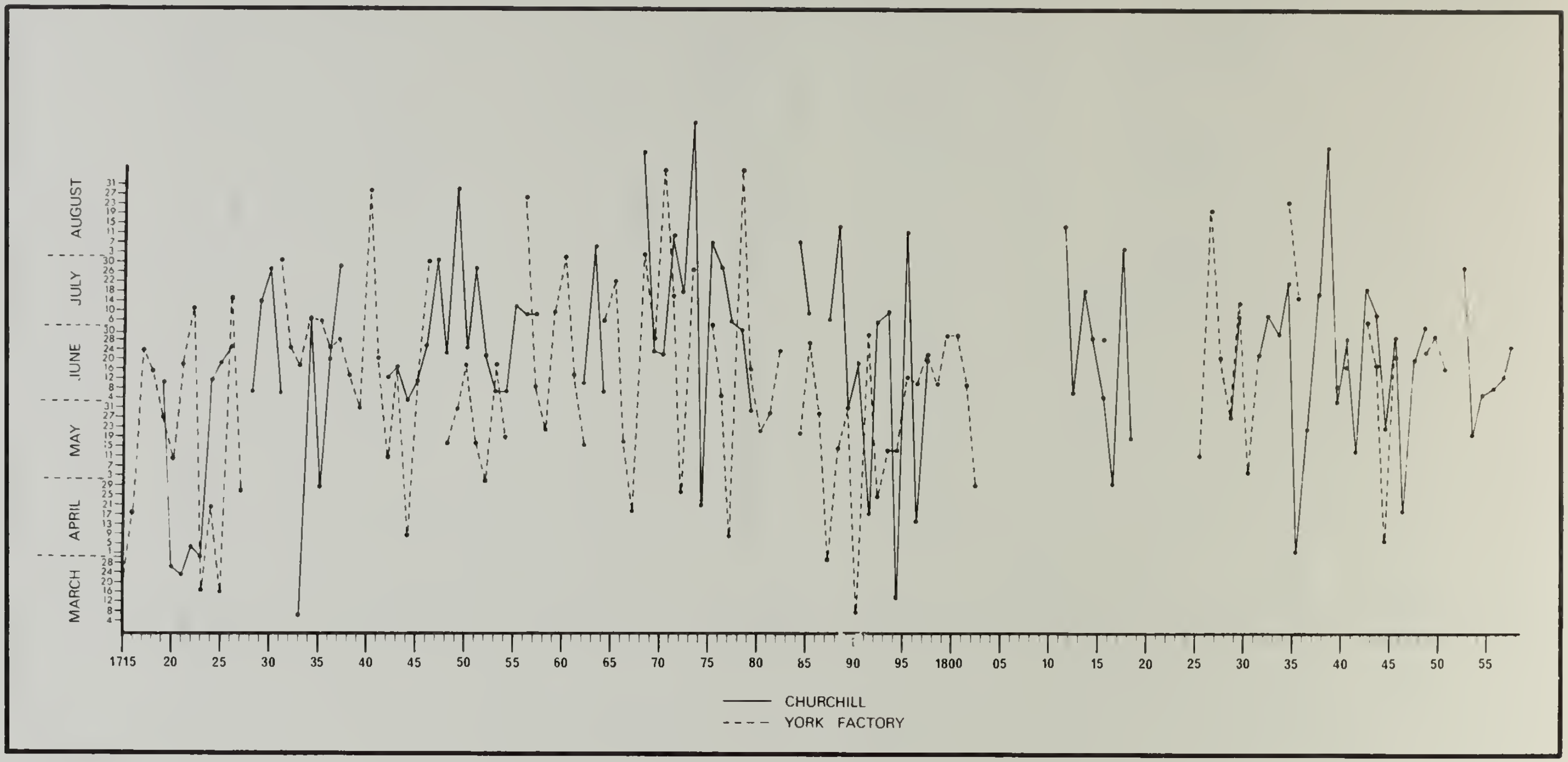

FIGURE 19: *Date of first thunder in summer, Churchill and York Factory (1715-1860).*

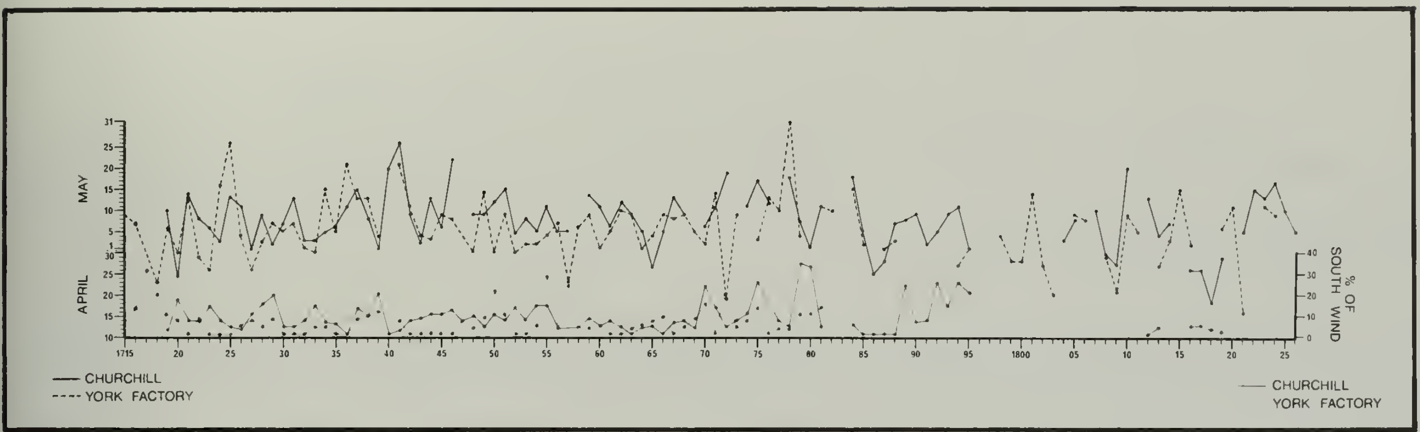

FIGURE 20: *Date of first sighting of geese, compared with percentage frequency of south winds, Churchill and York Factory (1715-1826).*

plot of the percentage frequency of south winds. A cursory study of the graphs suggests that there is homogeneity between the York Factory and Churchill Factory arrival dates. Further, there is an apparent relationship between the graph of first sighting of geese in spring and the occurrence of a higher percentage of south winds. When southeast and southwest wind percentages are also studied, more of the early arrival dates are accounted for. This hypothesis will be tested statistically later.

Frequencies of Precipitation Events

The frequencies of occurrence of rain in summer and snowfall in winter have been enumerated to date on a monthly and annual basis.

Number of Days with Rain in Summer

The total number of days on which rain was recorded for the period from June 1 to October 31 is shown in Figure 21. Modern records indicate the Churchill region generally receives rain on a fewer number of days than York Factory. However, it is interesting to note in Figure 21 that the difference between the two stations appears to change through time.

Some general observations regarding the trends are noteworthy:

(1) The curves apparently follow the same trends with the number of days showing a gradual decrease from 1715 to approximately 1765. From that point the curves rise rapidly to a peak at about 1780, then decline until 1800. Unfortunately, there is a gap between 1800 and 1820, which from all available indications, was an extremely interesting climatic period. When the curves begin again in 1820 they appear to approximate the levels of rainfall previously seen in the period from 1740 to 1750, except that the variability about the mean is greater.

(2) The second significant feature of the curves is the separation that begins in 1755 and reaches a maximum difference in 1765. From that year on, the difference remains relatively constant until the available data terminate about 1800. A similar difference is seen between snowfall curves for York Factory and Churchill, however, the separation is not so prolonged, spanning from 1762 to 1780.

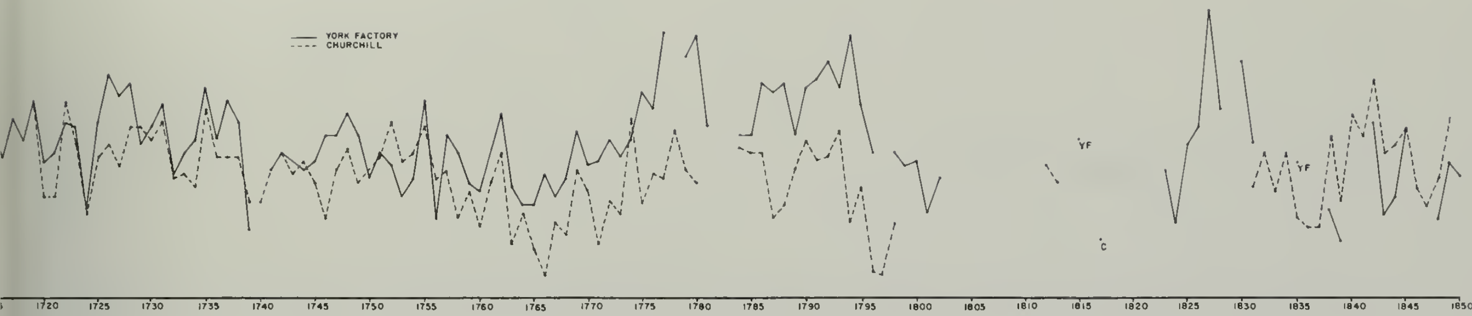

FIGURE 21: *Numbers of days per year with rainfall, June through October, York Factory and Churchill (1715-1850).*

The disparity between the two curves in Figure 21 could be attributed to changes in journalists at one or both of the stations. The difficulty with this proposition is that while the journalists changed at both locations none of these changes appears to be coincident with the times of variation in the record.

A second possibility is that the changes are attributable to changes in the locations where the journals were kept. York Factory was moved in 1791 a distance of approximately one mile (1.6 km). Churchill Factory occupied two locations, the first being at the original Churchill Factory from 1718 to 1739 and again from 1783 onwards, the second at Fort Prince of Wales from 1740 to 1782. Again, none of these dates are coincident with changes observed in the curves.

Number of Days with Snowfall in Winter

Figure 22 indicates the total number of days on which snow was recorded for the period from October 1 to May 31. In the computer count of these totals, there was no attempt to distinguish between different types of snowfall. A later count will be carried out to determine the number of days on which heavy or continuous snowfall occurred.

Some general observations that can be made on these data are as follows:

(1) There is a much greater degree of variation in the number of days of snowfall than there is in the number of days with rainfall.

(2) The curves show a gradual decline in the number of days of snowfall over the whole span from 1715 to 1850. This decline is apparent at both locations.

(3)Homogeneity is apparent between the two curves, however, it is not as distinctive as that in the rainfall curves. This is probably attributable to the very localized occurrence of snow showers originating from open water in Hudson Bay, particularly in the fall and spring.

(4) As previously mentioned there is a separation of the curves between 1763 and 1780.

It seems reasonable to suggest that homogeneity of the records is encouraging, and is evidence that the post journals are capable of providing valid phenological and climatic information. Secondly, there is evidence of relatively long-term climatic changes that may be compared to such changes determined by other researchers, both in the region of Hudson Bay and other areas of the world.

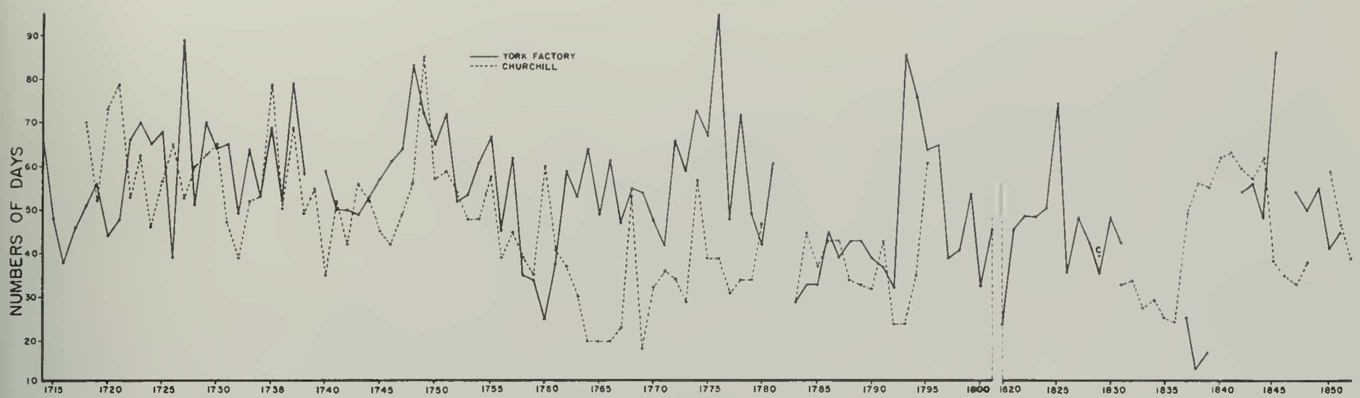

FIGURE 22: *Numbers of days per year with snowfall, October through May, York Factory and Churchill (1714-1852).*

Finally, the possibilities of determining meteorological causes for these changes will be greatly enhanced when frequencies of other indicators, particularly wind directions, are plotted and synthesized with the present information.

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