# Climatological Bulletin

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# Bulletin climatologique

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Les auteurs peuvent choisir de soumettre leurs manuscrits aux "Articles", "Notes de Recherches", ou "Nouvelles et Commentaires". Ils doivent l'indiquer sur la lettre d'accompagnement du manuscrit. Les articles de recherche et les "Notes" sont indépendamment soumis à l'examen d'au moins deux appréciateurs anonymes. Le rédacteur en chef examine les "Nouvelles et Commentaires" conjointement avec le comité de rédaction. On accepte les articles soit en français, soit en anglais. Il faut envoyer un résumé, de préférence en français et en anglais.

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LA PAGE DE TITRE doit comprendre: nom, prénoms des auteurs, ainsi que les affiliations professionnelles.

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LE TEXTE. Il faut taper à double interligne, sur des pages numérotées, le texte des articles plus longs et le diviser en sections, chacune dotée d'une en-tête à part et numérotée dans l'ordre. Il faut dactylographier l'en-tête de section sur une ligne à part.

LES REMERCIEMENTS doivent être dactylographiés sur une page à part, après le texte.

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# Foreword / Avant-Propos

In Volume 17(2), I used this space to talk about climatic change, a topic of considerable importance to climatologists and other researchers with an interest in climate. The use of traditional and newer forms of proxy data was highlighted. This is an area where great efforts have been expended in recent years, with remarkable creativity exhibited in the use of both "natural" and "historical" types of proxy data. Many examples can be found in the National Museums of Canada series on climatic change (Syllogeus 26, 33, 49, 51, 55).

Studies of short-term (decades-centuries) changes in Canada have been accomplished with the aid of instrumental records and both types of proxy data. These studies have become extremely important in light of current concerns about the possible impacts of future climatic changes, especially on Prairie agriculture, coastlines, Arctic environments, and the Great Lakes. No one guarantees that the past is an analogue of the future, but it does help to define the possibilities, given the uncertainties which prevail in general circulation modelling.

Volume 19(2) includes articles by Leduc and Lamothe on recent visibility trends, and Guiot on temperature and pressure trends since 1700. These studies present results that are influenced by both natural and societal forces. Is it possible to determine the relative contributions of these forces to climatic change? In our analyses, can we separate the natural fluctuations in our climate from the effects of increased industrialization, urbanization, and deforestation? Is there a "$CO_2$ signal" in these trends?

Our ability to advise policy makers about future climate and its possible impacts on society depends on how well we meet the challenges of climatic change research.

*Stewart J. Cohen*

# Tendances à long terme de la visibilité dans l'axe Windsor / Sept-Îles

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[Manuscrit reçu le 26 novembre 1984; révisé le 14 mars 1985]

RESUME

On a examiné la tendance à long terme de la visibilité durant la période 1953-1981 à 8 stations du sud du Québec et de l'Ontario à l'aide d'une partie des observations diurnes pour lesquelles on ne rapportait ni précipitation ni humidité relative supérieure à 90%. L'analyse a été faite en considérant les moyennes mobiles triennales de la visibilité correspondante au 60ième centile de la distribution saisonnière ou annuelle. Celle-ci montre la présence d'un creux en 1968-1970, lequel est bien marqué dans le centre et l'est de la région étudiée. L'analyse saisonnière révèle que les fluctuations sont plus marquées en été et que depuis le creux de 1968-1970, la visibilité est meilleure en hiver contrairement à la période antérieure.

ABSTRACT

Long term visibility fluctuations were examined during the period 1953-1981 at eight stations in southern Quebec and southern Ontario with diurnal observations from which were excluded hours with precipitation or relative humidity greater than 90%. The analysis was done by considering three-year moving averages of 60th percentile visibilities obtained on seasonal (winter, summer) and annual distributions. It shows a minimum in the years 1968-1970 which is well identified in the center and the east of the region studied. Seasonal analysis reveals that the fluctuations are more pronounced in summer and that since 1968-1970, visibilities are better in winter than in summer.

## 1. INTRODUCTION

La visibilité est une mesure de la transparence de l'air sur une échelle horizontale et correspond à la distance à laquelle un objet de dimensions convenables peut être vu et identifié. La visibilité est évaluéee à l'aide de repères, spécifiques à chaque station (montagnes, édifices, etc.) et elle est mesurée en milles. Les visibilités supérieures à plus de 15 milles ne peuvent être rapportées que si des repères appropriés existent (Environnement Canada, 1977); s'ils n'existent pas, on rapporte "15+". Notons cependant que de 1957 à 1961 les visibilités de 15+

n'étaient pas utilisées; durant cette période on estimait plutôt les visibilités supérieures à 15 milles en l'absence de repères au-delà de cette distance.

La visibilité est souvent considérée comme un indice de la qualité de l'air puisque, hormis la réduction attribuable aux phénomènes météorologiques, elle est fonction de la quantité d'aérosols présents dans l'air. Les obstacles à la visibilité générés par les activités industrielles résidentielles, minières, etc. sont les fumées, les poussières et la brume sèche. Les régions fortement urbanisées ou industrialisées souffriront donc d'une réduction marquée de la visibilité. Par exemple, pour la région de l'est des Etats-Unis on note une détérioration de la visibilité au cours des années '60 (Sloane, 1982b), suivie d'une amélioration après 1970 que l'on attribue au programme d'assainissement de l'air institué par le gouvernement américain.

On montre ici les tendances à long terme de la visibilité dans l'axe Windsor-Sept-Îles, couloir souvent considéré comme récepteur de la pollution générée plus au sud. La réduction de la visibilité comme on l'examine ici peut être associée au transport à longue distance des polluants atmosphériques et ainsi elle est étroitement liée au phénomène des précipitations acides.

## 2. MÉTHODE ET RÉSEAU

La méthode généralement appliquée pour analyser la tendance de la visibilité est le centile cumulé. Le nième centile cumulé correspond au pourcentage du temps qu'un seuil de visibilité est atteint ou dépassé; Sloane (1982a) suggère l'utilisation du 60ième centile pour détecter les variations à long terme de la visibilité. Pour chaque année (ou saison) on a obtenu la visibilité correspondant au 60ième centile en cumulant les fréquences pour chacune des 16 classes définies

TABLEAU 1: Délimitation des classes de visibilité (en milles).

| (milles) | Classe |
|---|---|
| 40+ | 1 |
| 35-39 | 2 |
| 30-34 | 3 |
| 25 | 4 |
| 20-24 | 5 |
| 15-19 | 6 |
| 12-14 | 7 |
| 10-11 | 8 |
| 8-9 | 9 |
| 7 | 10 |
| 6 | 11 |
| 5 | 12 |
| 4 | 13 |
| 3 | 14 |
| 1,5-2,5 | 15 |
| 0-1,25 | 16 |

au tableau 1 puis en interpolant entre deux classes successives. Toutefois, lorsque la fréquence de distribution n'a pas été extrapolée (vers les hautes visibilités) au contraire de Sloane (1982a). Dans ces cas, les fluctuations de la visibilité pouvaient se produire à des valeurs supérieures à celles du repère le plus éloigné. Pour cette raison, les séries des valeurs de visibilité ne sont donc pas nécessairement complètes à toutes les stations (voir figure 2 et 3 pour Ottawa, London et Sept-Îles).

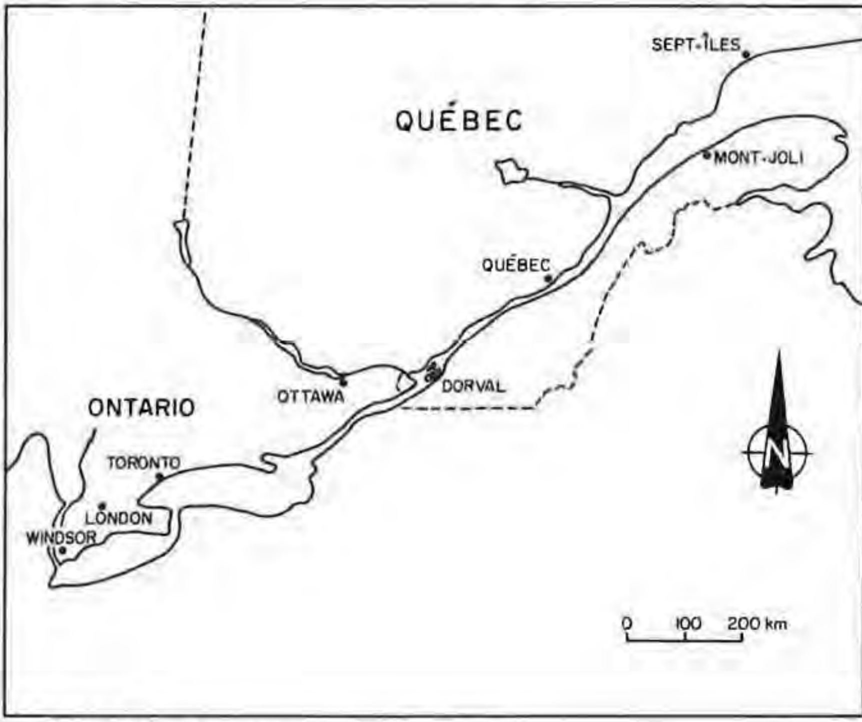


FIGURE 1 Réseau des stations

Les analyses ont été effectuées pour huit stations réparties dans le sud du Québec et de l'Ontario (figure 1), et pour 29 années de mesures (1953-1981) (tableau 2). Dans le but d'éliminer les influences météorologiques sur la visibilité, on a exclu les observations avec précipitation ou avec humidité relative supérieure à 90% (Sloane, 1982a). De plus, seules les observations de jour (9:00 à 14:00 HNE) ont été considérées alors que Sloane (1982a) utilise les observations de 10h, 13h et 16h. Le tableau 2 donne le nombre d'observations totales disponibles pour chaque station. Pour l'analyse saisonnière, les mois de décembre, janvier et février ont été retenus pour la saison d'hiver, et ceux de juin, juillet et août pour la saison d'été. Mentionnons qu'un changement dans la procédure d'observation à St-Hubert (25km à l'est de Dorval) nous a forcé à exclure cette station de notre analyse.

TABLEAU 2: Nombre d'observations (après restrictions), visibilité maximale et périodes d'observations des stations.

| Stations | Nombre d'observations (après restrictions) | Visibilité maximale (milles) | Période d'observations |
|---|---|---|---|
| Windsor | 51608 | 15+ | 1953-81 |
| London | 47298 | 15+ | 1953-81 |
| Toronto | 51430 | 1953-63 15+ | 1953-81 |
| | | 1964-81 25+ | |
| Ottawa | 51026 | 1953-61 15+ | 1953-81 |
| | | 1962-81 25+ | |
| Dorval | 50894 | 50+ | 1953-81 |
| Québec | 48540 | 55+ | 1953-81 |
| Mont-Joli | 47283 | 45+ | 1953-81 |
| Sept-Îles | 46525 | 35+ | 1953-81 |

## 3. TENDANCES DE LA VISIBILITÉ

### 3.1 *Tendances annuelles*

La figure 2 donne les moyennes mobiles triennales du 60ième centile des distributions annuelles; celle-ci démontre clairement un gradient de visibilité du SUD-QUEST vers le NORD-EST. Alors qu'à Windsor et London la visibilité se situe autour de 10 milles, elle varie de 15 à 20 milles à Toronto et Ottawa. A Québec, elle est presque toujours supérieure à 20 milles.

Le profil des variations inter-annuelles du 60ième centile permet de rassembler les stations en quatre groupes: 1-Windsor, London; 2-Toronto, Ottawa, Québec; 3-Dorval; 4-Mont-Joli, Sept-Îles.

Dans le sud de l'Ontario (groupe 1), on remarque une constante amélioration de la visibilité de 1953 à 1981, graduelle dans le cas de Windsor et légèrement fluctuante à London.

Dans la région centrale du territoire étudié (groupes 2 et 3), la visibilité a subi de fortes variations. Ainsi Toronto et Québec (groupe 2) montrent une baisse de leur visibilité au début des années '60. De plus, les trois stations du groupe 2 indiquent un maximum secondaire en 1964-66, suivi d'un creux en 1968-71, ce dernier étant accentué à Ottawa et Québec. La période 1975-77 marque la meilleure visibilité puisque toutes les stations du groupe 2 parviennent à leur maximum. Ce groupe montre une augmentation générale, quoique faible, de la visibilité malgré ces variations.

Dorval (groupe 3) est la seule station qui ne montre pas de tendances établies pendant ces 29 années. Elle indique sensiblement les mêmes tendances que le groupe 2 (notamment le creux de 1970), mais la visibilité y décroît fortement à partir de 1975, atteignant en 1980 une valeur égale à 1954. A Dorval, la visibilité ne s'est donc pas améliorée pendant la période considérée.

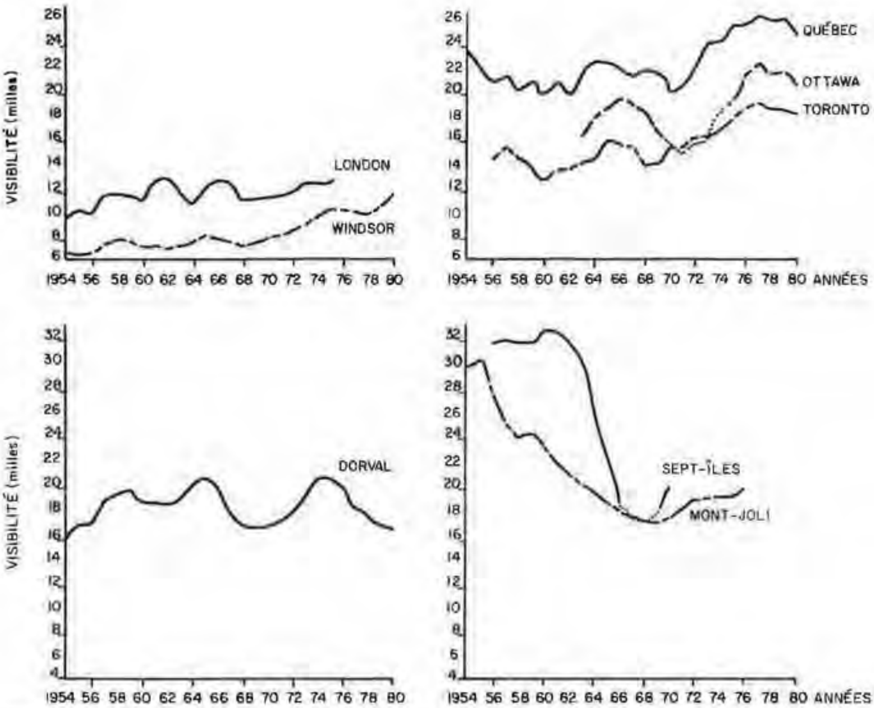


FIGURE 2 Moyennes mobiles triennales du 60ième centile annuel

Les stations dans l'Est du Québec (groupe 4) se caractérisent par une forte décroissance autour des années '60 pour atteindre un creux en 1967-69. Par la suite, la visibilité aurait augmenté (surtout à Sept-Iles). A ces deux stations, la visibilité se situe à environ 30 milles au début et à la fin de la période d'analyse.

En fait, les stations du sud-ouest (Windsor, London, Toronto, Ottawa, Québec) marquent une hausse de la visibilité comme Sloane (1982b) le notait pour la région du nord-est américain. Dorval constitue une exception, la visibilité fluctuant beaucoup mais ne s'améliorant pas à long terme.

Ces résultats s'accordent en général avec les conclusions des études effectuées pour l'est des Etats-Unis (Sloane, 1982b) pour le creux de 1970 et le maximum de 1975-77; le maximum des années '55 (tendance majeure dans l'analyse de Sloane) est cependant peu marqué dans cette analyse, et il ressort que les années '60 ont connu des variations plus importantes.

### 3.2 *Tendances saisonnières*

Les figures 3a et 3b mettent en évidence la variation de la visibilité entre les stations selon les saisons. En saison hivernale (figure 3a), on observe à nouveau

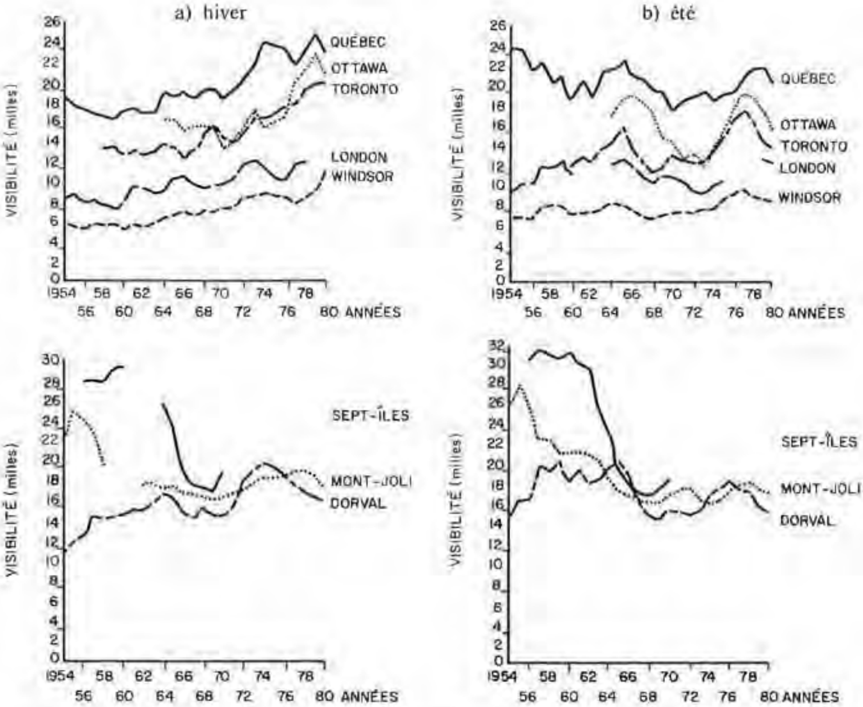


FIGURE 3 Moyennes mobiles triennales du 60ième centile saisonnier

un gradient de visibilité de Windsor vers Québec. Les stations des trois premiers groupes sont principalement caractérisées par une amélioration de leur visibilité entre le début et la fin de la période; aux stations des groupes 2 et 3, on note une augmentation particulièrement importante à partir du début des années '70. Aux stations du groupe 4, la variation hivernale est un reflet assez fidèle de la variation annuelle mais contrairement aux autres groupes, la visibilité a connu une baisse entre le début et la fin de la période analysée.

En été (figure 3b), les variations du 60ième centile sont très accentuées mais aucun changement ne semble se dessiner entre le début et la fin de la période. Aux stations du groupe 1, on note une stabilité de la visibilité mais celles des groupes 2 et 3 amplifient les creux et les crêtes de la courbe annuelle. Les stations du groupe 4 se comportent de la même façon qu'en hiver. Aux stations du groupe 2, il semble donc que le maximum de 1965 et le creux de 1970 soient spécifiques à la saison estivale.

Les tendances saisonnières indiquent également un fait particulièrement intéressant: avant le creux de 1970, la visibilité était meilleure en été, comparativement aux années '70 où la visibilité est meilleure en hiver. Les figures de Sloane (1982b) indiquent un phénomène analogue pour Chicago, Cleveland, Columbus et Dayton. Ainsi, le début des années '70 marque un point où les tendances saisonnières de visibilité sont inversées. La bonne visibilité hivernale est donc un fait relativement récent.

## 4. CONCLUSION

Cette analyse a permis de montrer l'existence des fluctuations de la visibilité en Ontario et au Québec, dont certaines avaient déjà été identifiées ailleurs (principalement le creux des années '70 et l'augmentation subséquente). Ces fluctuations sont relativement uniformes de Windsor à Québec; plus à l'est, Sept-Îles et Mont-Joli montrent une variation importante marquée par une décroissance rapide de 1960 à 1970.

D'après Bridge et Fairchild (1981), les faibles visibilités sont reliées aux épisodes de brume sèche caractérisés par de fortes concentrations de sulfates dont on attribue l'origine à la combustion du charbon. La consommation américaine des combustibles fossiles aurait connue des variations: une baisse entre 1950 et 1960, puis une hausse jusqu'en 1978. Fort curieusement, le creux de consommation en 1960 correspond à une baisse de visibilité, et l'augmentation de la consommation à une hausse de visibilité. Sloane (1982b) concluait que les concentrations de sulfates n'étaient pas le seul facteur influençant la visibilité.

Etant donné l'étendue de la région couverte par cette étude il y a lieu de croire que les facteurs régissant les fluctuations observées agissent sur une grande échelle. Les variations dans les émissions des polluants sont primordiales, mais les fluctuations de la circulation atmosphérique peuvent être tout autant significatives. D'ailleurs, Sloane (1983) concluait que les masses d'air estivales en 1971-75 étaient plus stagnantes et plus humides que celles de 1952-56, ce qui aurait eu pour effet de favoriser la transformation de sulfures en sulfates.

Les avenues de recherche visant à expliquer les tendances de la visibilité sont nombreuses. En premier lieu, une analyse des composants atmosphériques et de qualité de l'air à chaque station s'impose en vue de corréler ces données aux variations de la visibilité, ce qui permettrait de statuer sur la qualité de l'air en fonction du milieu local. Deuxièmement, une analyse approfondie de la circulation atmosphérique apporterait une meilleure compréhension des processus agissant sur la transformation et le transport à longue distance des polluants.

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# Corrigendum

In the article by J. Guiot, Vol. 19(2), there is an error in the figure captions on pages 26-29. The captions at the top of each page should read "a)", "b)", "c)", and "d)" respectively, not "Figure 2a", "Figure 2b", etc. The caption at the bottom of page 26, referring to Figure 3, is correct. The four pages thus show Figures 3a, 3b, 3c, and 3d respectively.

# Reconstruction of Seasonal Temperatures and Sea-level Pressures in the Hudson Bay Area back to 1700

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Original manuscript received 28 February 1985; in revised form 30 April 1985

ABSTRACT

The Hudson Bay region is rich in data useful to palaeoclimatology. Freeze-up and break-up series in the western Hudson Bay area, early meteorological measurements and tree ring series have been selected. The missing data are estimated, using the best correlated series, and from these, 23 continuous proxy series are deduced from 1700 to 1979. Sixty-seven series of seasonal temperature for the years 1925 to 1983 and 27 sea-level pressure series for the period 1953 to 1983 are produced. Temperature and presure fields are reconstructed on a seasonal basis from these proxy series using the standard transfer function. A relationship between principal components of the temperature network and the proxy series is developed for the 1925-1979 interval and extrapolated back to 1700. Temperature is deduced for six stations representative of the meteorological network. Verification tests are significant mainly for high frequencies. The trends are better estimated by an analogue method. Both kinds of reconstruction are combined and yield an improvement in results. The relationship between temperatures and pressures is used to reconstruct earlier pressure fields by the analogue method. The trend-analysis reveals that a warming occurred at the end of the 19th century. Eight classes are defined to show the main structure of the space and time variations of the temperature and pressure fields.

RESUME

La région de la Baie d'Hudson est riche en données susceptibles de fournir des informations paléoclimatiques intéressantes. Des séries de debâcle et d'embâcle de rivières de l'ouest de la Baie d'Hudson, des séries instrumentales reconstituées et sept séries dendrochronologiques ont été sélectionnées. Leurs lacunes sont comblées à l'aide des séries les mieux corrélées et finalement vingt-trois séries indirectes ("proxy data") complètes entre 1700 et 1979 en sont déduites. Soixante-sept séries de température saisonnières sont complétées entre 1925 et 1983 et vingt-sept séries de pressions entre 1953 et

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1983. Les champs thermiques et barométriques sont reconstruits sur une base saisonnière à partir de ces séries indirectes. Une première méthode est utilisée: la fonction de transfert classique. Elle consiste en le calcul d'une relation entre les composantes principales du réseau thermique et les séries indirectes sur la période 1925-1979. Celle-ci permet une extrapolation jusqu'en 1700 et un retour aux températures elles-memes via six stations représentatives du réseau. Des tests de vérification montrent le bon comportement des hiutes fréquences reconstruites. Une méthode de reconstruction par les plus proches analogues est alors utilisée avec un accent particulier sur les basses fréquences. Les deux types de reconstructions sont fondues, ce qui améliore nettement les résultats. Un lien est trouvé entre champ thermique et champ barometrique. Celui-ci est utilisé pour reconstruire les pressions en six stations également par la méthode des analogues. Les tendances des reconstructions sont finalement analysées, ce qui met en évidence un réchauffement à partir de la fin du 19ième siècle. Huit classes de température sont définies montrant les principales structures des variations spatiales et temporelles des champs thermique et barométrique.

## 1. INTRODUCTION

There are many areas of the world and many periods of history for which no climatic data exist. It is common now to use proxy data to substitute for these gaps. Dendroclimatology provides proxy records which are continuous and reliable. These are based on ring widths and wood densities for typical tree species. Dense networks of such data are now becoming available. As well, historical archives provide much interesting information including early instrumental observations, weather diaries and descriptive chronicles of regional human activities (Catchpole, 1980). While many of these historical data have gaps and other irregularities, they can be easily identified with specific climatic parameters. Fritts, Le Roy Ladurie and Lamb (see reviews in Fritts (1976), Le Roy Ladurie (1967) and Lamb (1977)) have performed a pioneer work in this field.

The variety of historical archives of the Hudson's Bay Company pertaining to the Hudson Bay area of Canada has given to the science a source of information unique in North America. After the important study of freeze-up and break-up of MacKay and Mackay (1965), a method called "Content Analysis", enabling the quantification of these descriptive accounts was developed. Several recent papers concerning this rich collection of data have been published: Moodie and Catchpole, 1976, Moodie, 1977, Moodie and Catchpole, 1975, Catchpole and Ball, 1981, Rannie, 1983. These apply particularly to freeze-up and break-up events of different rivers emptying into Hudson Bay. These 18th and 19th century instrumental data have been checked and quality-controlled by Ball and Kingsley (1984) and Wilson (1982, 1983) for, respectively, the southwest side and the east side of Hudson Bay. Using other sources, Hillaire-Marcel *et al.* (1981) have reconstructed climatological series back to 1840 for several cities in southern Canada.

Snow geese migrations were proposed by Ball (1983) as a means of reconstructing southerly winds for northern Manitoba. Some correlations are clear but problems arise because of possible mistaken identity or amalgamation of species by the Hudson's Bay Company observers (Davies, personal communication), and also because of the higher influence of weather conditions in southern Manitoba rather than in northern Manitoba.

Tree-ring indices are presented in Cropper and Fritts (1981) for Nouveau Québec and Labrador, by Parker *et al* (1981) and Payette *et al* (1984) for the eastern coast of Hudson Bay, and by Hansell *et al* (1984) for the western coast of Hudson Bay.

A first linkage between the biophysical and historical kinds of proxy data was attempted by Jacoby and Ulan (1982) who found a relationship between freeze-up dates of the Churchill River and tree-ring series. The reconstruction of these dates does not show any trend, which is contrary to our own reconstructions as will be demonstrated later.

The aim of this paper is to use systematically both kinds of proxy data for producing reliable climatic series. The amalgamation of the reliable but discontinuous historical series with the continuous, widespread, but not always perfectly understood tree-ring series, is conceptually a synergistic tool for paleoclimatological research.

First, a statistical method, the transfer function, is employed. Introduced by Imbrie and Kipp (1971) for planktonic foraminifera, and improved by Fritts *et al* (1971) and Blasing (1978) for tree-rings, this method is based on a calibration of a regression between recent climatic series and tree-ring series and the extrapolation of the climatic series using the corresponding tree-ring data. The reconstructions will be improved here by the analogue method suggested by Alt (1983).

## 2. PROXY DATA

The first group of data which is taken from Moodie and Catchpole (1975) consists of freeze-up and break-up dates of rivers entering the western shore of Hudson and James Bays. Several categories have been defined by the authors for coding and three are used here: first freeze-up (cat. 1), complete freeze-up (cat. 3), first break-up (cat. 5). Six locations are used: (i) Churchill Factory 1 (1718-1739 and 1783-1866); (ii) Churchill Factory 2 (1740-1782); (iii) York Factory 1 (1714-1791); (iv) York Factory 2 (1791-1851); (v) Fort Albany (1721-1867); (vi) Moose Factory (1736-1871). The Churchill and Moosonee series have been extended to the modern period using recent data (Allen, 1977). Locations are given in Figure 1.

A second group of data is provided by Rannie (1983) for the Red River at Winnipeg (1798-1981): (i) freeze-up dates from October 1; (ii) break-up dates from March 1.

Ball and Kingsley (1984) provide monthly temperature data for

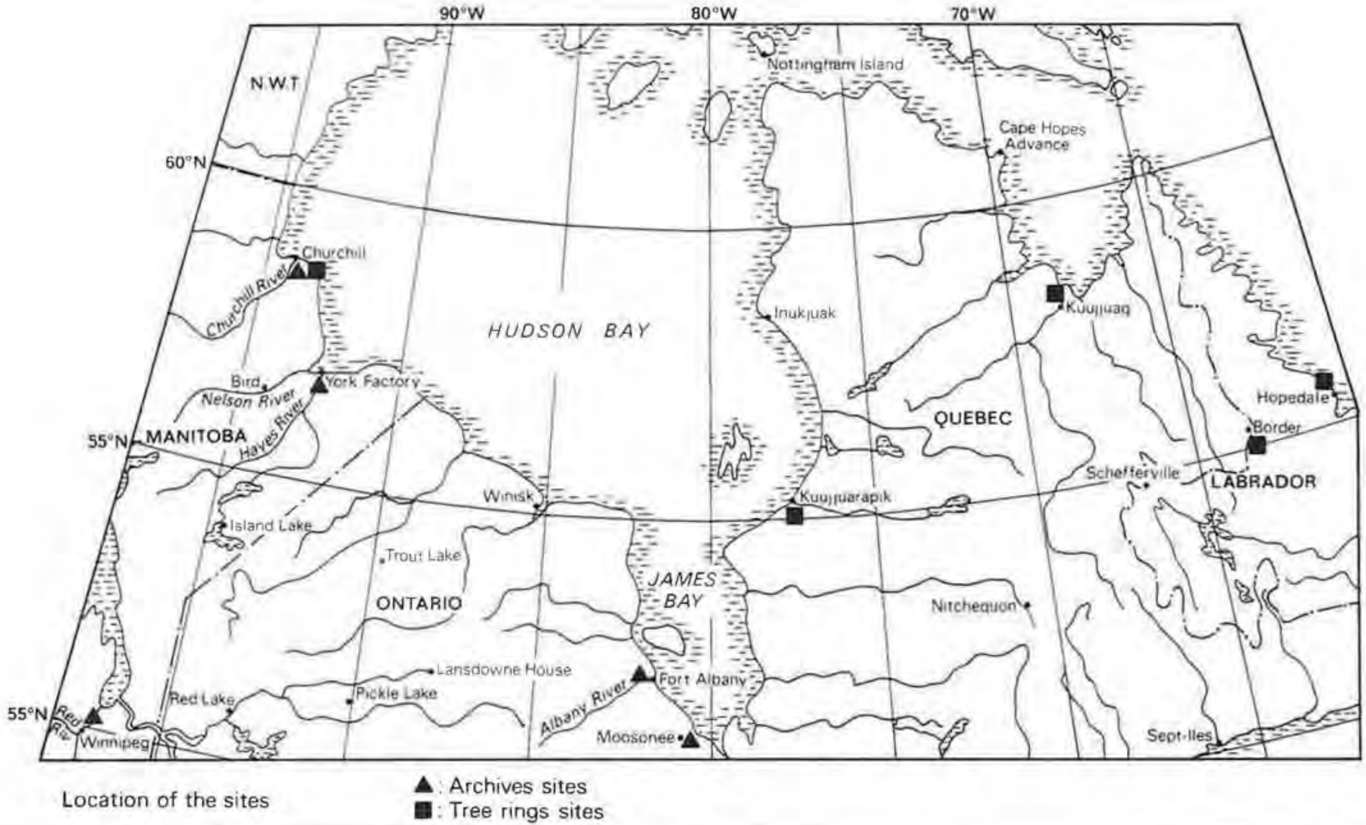



FIGURE 1. Location of the sites

York Factory (1774-1910) and Churchill Factory (1768-1769 / 1811-1858). The York Factory series are the most numerous, but the Churchill data can be connected to recent observations (1932-1983). These two monthly series have been transformed into eight seasonal series: winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

Seven tree-ring series are added (Figure 1). Three are taken from Cropper and Fritts (1981): (i) white spruce ring width indices from Nain, Labrador, 1769-1973; (ii) white spruce ring width indices from Border Beacon, Labrador, 1660-1976; (iii) larch ring width indices from Fort Chimo (now Kuujjuaq), Quebec, 1650-1974. Also, two are taken from Parker *et al* (1981): Cri Lake, Quebec (near Poste-de-la-Baleine, now Kuujjuarapik) -ring width and maximum density indices. Finally, chronologies developed by P. Scott and collaborators (Hansell, 1984) in the Churchill region (Manitoba) are used: (i) open forest ring width indices for trees older than 160 years, 1691-1982; (ii) forest-tundra ring width indices, 1663-1982.

Figure 1 presents the location of the different series and, in Table 1, the identifying information for these 35 series and the most significant elements of their correlation matrix are shown.

All of these series are affected by considerable missing data, but Table 1 shows that some are satisfactorally correlated anyway. It is thus possible to estimate much of these missing data in the following way. The correlation matrix of the 35 series is computed element by element on the maximum number of observations available for each pair. The eigenvectors and eigenvalues are then computed. The missing data are replaced, after scaling, by the corresponding observation of the most correlated series, if it exists. If it does not, the next most highly correlated variable is used. This allows for deduction of the amplitudes or time variations of the principal components. Only the first 14 principal components seem to be useful to reproduce, with a small account of noise, the raw data by inverse transformation; more details are given in Guiot (1985b - in press). Thus, 35 series, complete for the period 1700-1979, are constructed. The quality of the estimation of missing data is verified by the comparison of estimated and actual values when they are available. The correlations calculated in this way range between 0.70 and 0.92, except one (for CHSP: 0.40), which are highly significant.

Further verification of the quality of the estimated data is given by computing correlations between series representing similar climatic factors (Table 2). These indicate very good results. In order to minimize local factors, the 28 historical series are merged into these 15: The three categories for Churchill 1 and 2 are reduced to 3 series (CHU1, CHU3, CHU5); same for York (YOR1, YOR3, YOR5); Albany and Moosonee are condensed into one station (MOO1, MOO3, MOO5); the two river ice series in Winnipeg, WINB and WINF are kept integrally; and the temperatures for Churchill and York are averaged (CYWI, CYSP, CYSU, CYAU). The annual mean is denoted by CYAN. These 16 series and the 7 series of tree-ring ones are shown as Figure 2a to 2d. Figure 2a also

TABLE 1 The proxy series and the most significant correlations (number of degrees of freedom).

| name | | label | correlation 1 | | correlation 2 | |
|---|---|---|---|---|---|---|
| Churchill 1 | cat 1 | CH11 | CH21 | 0.94 (5) | CHAU | 0.67 (24) |
| | cat 3 | CH13 | CH23 | 0.84 (54) | YO13 | 0.45 (54) |
| | cat 5 | CH15 | CH25 | 0.88 (85) | YTSP | –0.47 (19) |
| Churchill 2 | cat 1 | CH21 | CH11 | 0.94 (5) | YTAU | 0.85 (5) |
| | cat 3 | CH23 | CH13 | 0.84 (54) | YTAU | 0.66 (8) |
| | cat 5 | CH25 | CH15 | 0.88 (85) | YTSP | –0.51 (27) |
| York 1 | cat 1 | YO11 | MOO1 | 0.31 (51) | CH21 | 0.38 (38) |
| | cat 3 | YO13 | ALB3 | 0.56 (71) | YTAU | 0.94 (6) |
| | cat 5 | YO15 | YO25 | 0.94 (7) | YTSP | –0.58 (10) |
| York 2 | cat 1 | YO21 | CHWI | 0.68 (10) | CH23 | 0.64 (8) |
| | cat 3 | YO23 | MOO3 | 0.70 (36) | YTAU | 0.68 (13) |
| | cat 5 | YO25 | YO15 | 0.94 (7) | MOO5 | 0.52 (45) |
| Albany | cat 1 | ALB1 | MOO1 | 0.76 (130) | YTAU | 0.70 (23) |
| | cat 3 | ALB3 | MOO3 | 0.65 (115) | ALB1 | 0.65 (141) |
| | cat 5 | ALB5 | MOO5 | 0.86 (130) | YO25 | 0.49 (45) |
| Moosonee | cat 1 | MOO1 | ALB1 | 0.76 (130) | YTAU | 0.71 (23) |
| | cat 3 | MOO3 | ALB3 | 0.65 (115) | YO23 | 0.70 (36) |
| | cat 5 | MOO5 | ALB5 | 0.86 (130) | YO25 | 0.49 (45) |
| Winnipeg | freeze-up | WINF | MOO1 | 0.45 (54) | YTAU | 0.50 (28) |
| | break-up | WINB | YO25 | 0.52 (45) | YTSP | –0.46 (29) |
| York temp. | winter | YTWI | WINB | –0.34 (38) | MOO5 | –0.34 (31) |
| | spring | YTSP | WINB | –0.44 (33) | CH25 | –0.48 (23) |
| | summer | YTSU | CHSU | 0.89 (4) | YTWI | –0.34 (23) |
| | autumn | YTAU | YO13 | 0.94 (6) | MOO1 | 0.71 (23 |
| Churchill | winter | CHWI | YO25 | –0.52 (10 | YTSP | –0.62 (6) |
| | spring | CHSP | YO25 | –0.74 (9) | CHSU | 0.45 (57) |
| | summer | CHSU | YO23 | 0.65 (8) | YTSU | 0.89 (4) |
| | autumn | CHAU | YO21 | 0.86 (8) | CH11 | 0.67 (24) |
| TREE-RING SERIES | | | | | | |
| Border Beacon (Lab) | | BEAI | NAII | 0.42 (280) | CH23 | –0.32 (55) |
| Fort Chomo (Québec) | | CHII | CRII | 0.32 (280) | YTSU | 0.37 (42) |
| Lac Cri (Qué) width | | CRII | CRID | 0.30 (280) | CHSP | –0.28 (64) |
| Lac Cri (Qué) dens. | | CRID | NAII | 0.26 (280) | CHSU | 0.25 (60) |
| Nain (Lab) | | NAII | BEAI | 0.42 (280) | CHSP | –0.31 (64) |
| Churchill open forest | | CHOF | YO25 | –0.50 (45) | CHSU | 0.22 (60) |
| Churchill for. tundra | | CHFT | YO13 | –0.33 (77) | YTSU | 0.40 (42) |

TABLE 2. A few correlations between completed series.

| variables | corr. | variables | corr. | variables | corr. |
|---|---|---|---|---|---|
| CH11-VH21 | 0.86 | CH13-CH23 | 0.78 | CH15-CH25 | 0.86 |
| YO11-YO21 | 0.81 | YO13-YO23 | 0.72 | YO15-YO25 | 0.80 |
| ALB1-MOO1 | 0.81 | ALB3-MOO3 | 0.76 | ALB5-MOO5 | 0.87 |
| YOWI-CHWI | 0.61 | YOSP-CHSP | 0.68 | YOSU-CHSU | 0.61 |
| YOAU-CHAU | 0.75 | | | | |

a) Freeze-up and break-up dates: Churchill Factory, York Factory. (Julian Date)

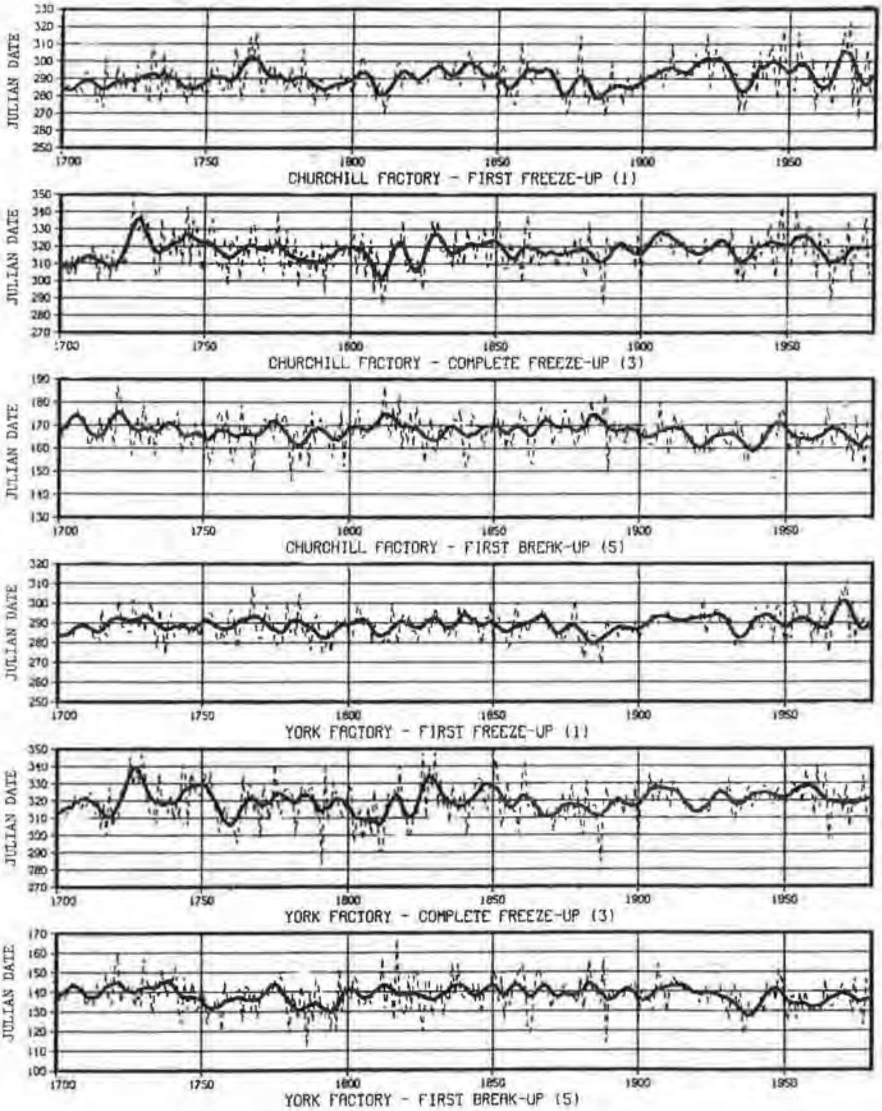
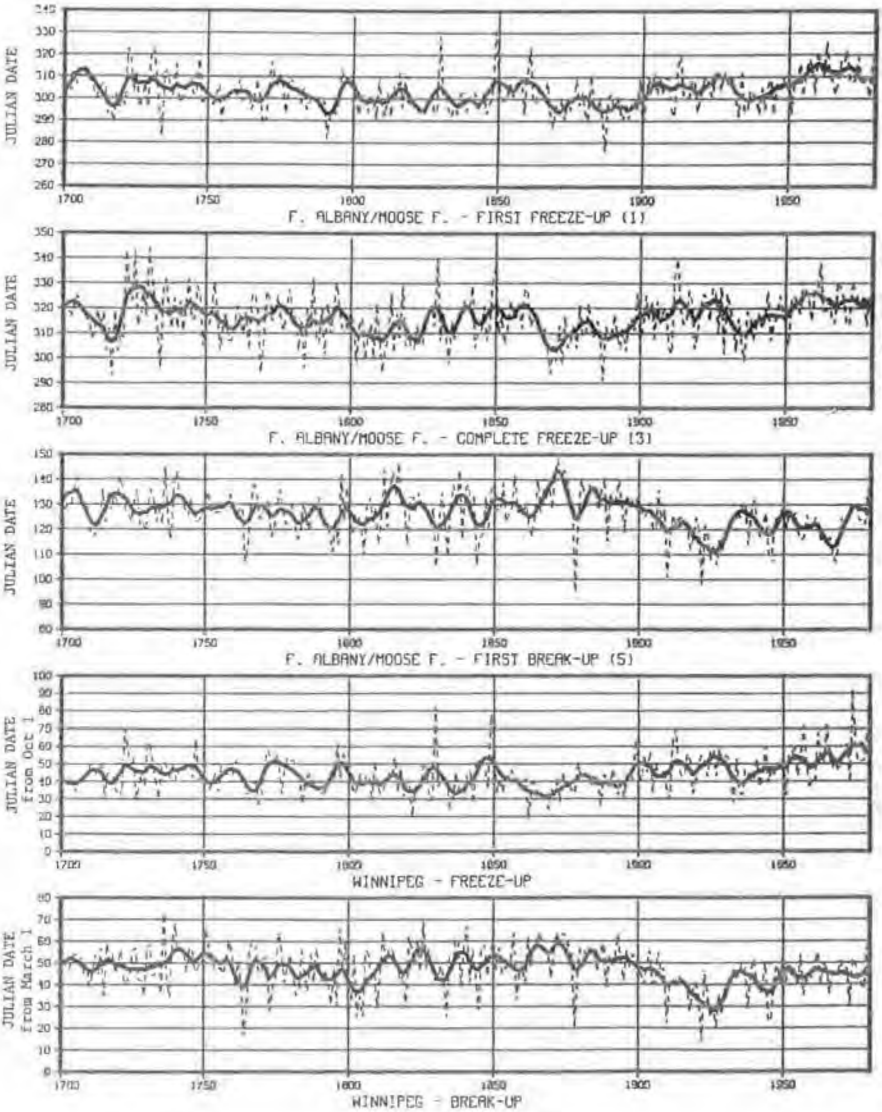
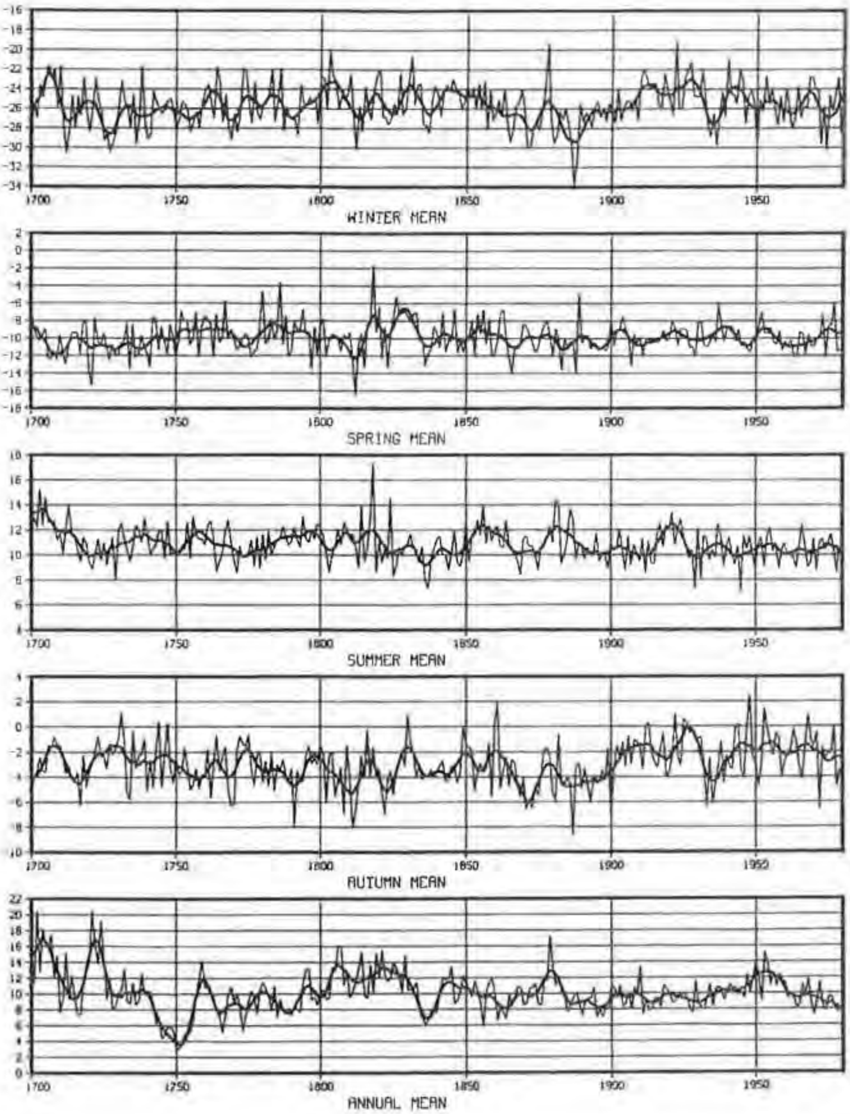



FIGURE 2. Proxy series used for the climatic reconstructions: the missing data have been estimated and some series have been averaged (see text).

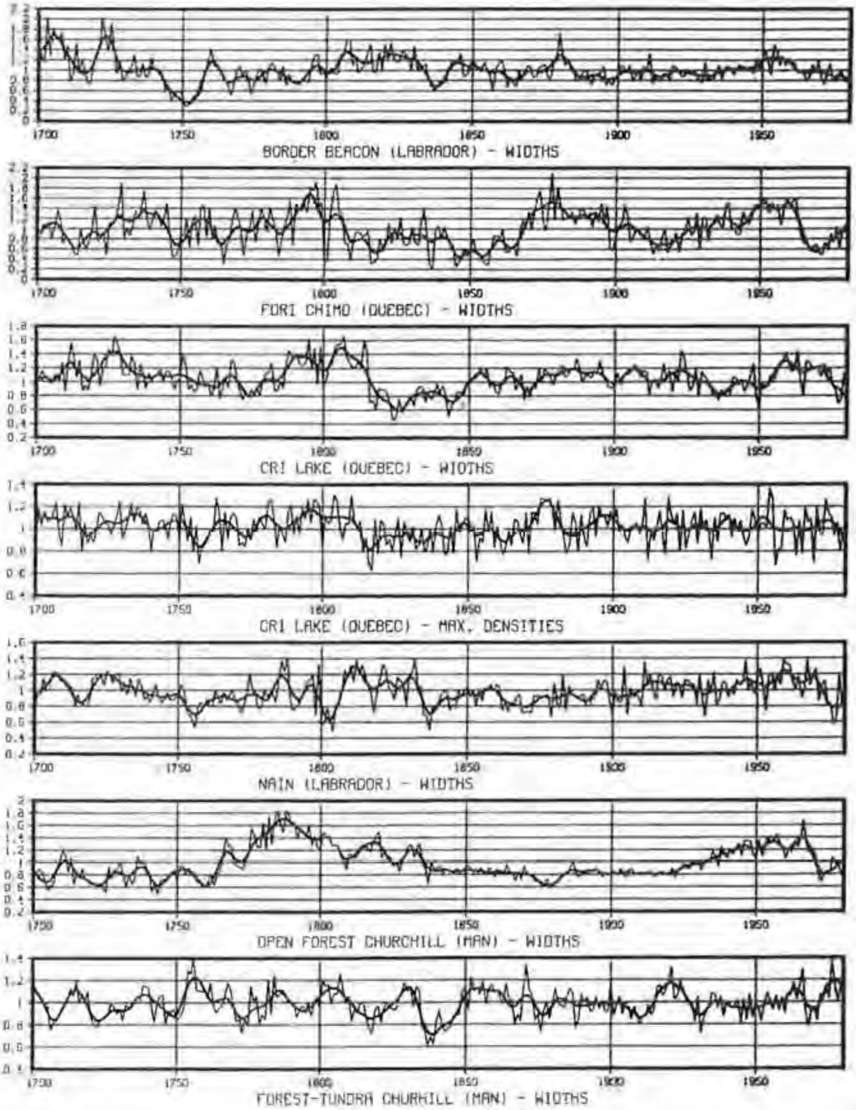
b) as in a: Fort Albany, Moose Factory. (Julian Date)



c) Temperatures at Churchill/York Factory (°C).



d) Tree-ring indices.



shows clearly that the freeze-up dates have a positive trend from 1880, contrary to the reconstruction of Jacoby and Ulan (1982). If the calibration (1741-1764) of these authors is examined, it is clear that late freeze-up during the period 1741-1750 is underestimated and early freeze-up during the period 1750-1764 is overestimated. The break-up dates show the same trend. These are related to an increase of spring and autumn temperatures. In Winnipeg the increase seems to begin 10 years earlier. The temperature series confirms the trend except for spring and summer (possibly an error in the estimations). For the tree-ring chronologies, different trends are identified and the maxima of the growth are not in the 20th century: internal plant processes and poor removal of the tree-growth trend may cause this discrepancy between ice and tree-ring data.

## 3. METEOROLOGICAL DATA

Between 61°W and 105°W and between 47°N and 73°N, the meteorological network of the Atmospheric Environment Service (AES) of Canada is composed of 67 stations with long series of air temperatures and 27 with sea-level pressure (SLP) (Table 3). Although the analysis period is restricted to 1925-1983 for temperatures and 1953-1983 for SLP, the many missing data (between 10 and 50 % according to the station) may bias the results. The missing data are estimated using the corresponding data of the most correlated station.

A further check on the validity of the reconstructions is to subjectively decide whether the time / space patterns which emerge make sense from a synoptic climatology viewpoint. Recent trends of the Canadian climate are presented in Thomas (1975). A brief seasonal description of general patterns will help in the understanding of the final reconstructions.

In WINTER (DJF), low pressure often occurs over the Atlantic coast and a high pressure cell is located over the Yukon Territory. This induces a prevailing north-westerly flow. In early winter, a positive thermal anomaly (with respect to latitude) is located over the Hudson Bay eastern coast (Bryson and Hare, 1974) because of the delay in the freeze-up. Arctic air masses receive considerable heat and moisture from the Bay before reaching Quebec. The atmospheric circulation is essentially meridional. In SPRING (MAM), the main centre of the high in the west of the Bay shifts southeast and the Atlantic low pressure zone fills gradually (Hufty, 1982). The heating of the land mass in western Canada induces a strong thermal gradient from the Mackenzie River to James Bay (Bryson and Hare, 1974). The thermal anomaly over Quebec is now negative because of advection from Hudson Bay and the atmospheric circulation becomes more zonal. In SUMMER (JJA), the Arctic Front has a mean trajectory close to the tree-line (extending southeast from Churchill to Nouveau Québec through James Bay). A negative thermal anomaly is located over Hudson Bay and over northern land regions having continuous permafrost. In AUTUMN (SON), the low pressure deepens again. Hudson Bay is not frozen until year-

TABLE 3. Meteorological stations used in the study. "p" indicates the use of the pressure data and "*" the absence of the temperature data. Latitudes and longitudes are given in degrees and minutes and elevations in meters.

| station | | lat. | long. | elev. | station | | lat. | long. | elev. |
|---|---|---|---|---|---|---|---|---|---|
| NORTH-WEST TERRITORIES | | | | | | | | | |
| Baker Lake | p | 64.10 | 96.00 | 0 | Chesterfield | p | 63.20 | 90.43 | 6 |
| Coral Harb | p | 64.12 | 83.22 | 64 | Ennadai Lake | p | 61.08 | 100.55 | 325 |
| Jenny Lind I. | | 68.39 | 101.44 | 37 | Pelly Bay | p | 68.26 | 89.46 | 326 |
| Sheppard Bay | | 68.49 | 93.26 | 51 | Arctic Bay | | 73.00 | 85.18 | 11 |
| Brevoort Isl. | | 63.21 | 64.10 | 371 | Broughton Isl. | | 67.33 | 63.47 | 598 |
| Cape Dyer | p | 66.39 | 61.23 | 723 | Cape Hooper | | 68.26 | 66.47 | 401 |
| Clyde | p | 70.27 | 68.33 | 6 | Dewar Lake | | 68.39 | 71.14 | 518 |
| Frobisher B. | p | 63.45 | 68.33 | 34 | Gladman Pt A | | 68.40 | 97.48 | 25 |
| Hall Beach A | p | 68.47 | 81.15 | 8 | Lake Harbour | | 62.50 | 69.55 | 16 |
| Longstaff B. | p | 68.57 | 75.18 | 162 | Mackar Inlet | p | 68.18 | 85.41 | 399 |
| Nottingham I. | p | 63.07 | 77.56 | 16 | Pond Inlet | | 72.41 | 77.59 | 4 |
| Spence Bay | * | 69.32 | 93.31 | 13 | | | | | |
| MANITOBA | | | | | | | | | |
| Brochet | p | 57.53 | 101.40 | 349 | Churchill | p | 58.45 | 94.04 | 29 |
| Gillam | | 56.21 | 94.42 | 138 | Norway House | | 53.59 | 97.50 | 219 |
| Wabowden | | 54.55 | 98.38 | 233 | Lynn Lake | * | 56.52 | 101.04 | 371 |
| Thompson | * | 55.48 | 97.52 | 215 | | | | | |
| ONTARIO | | | | | | | | | |
| Big Trout L. | p | 53.50 | 89.52 | 219 | Cent. Patricia | | 51.30 | 90.09 | 373 |
| Ear Falls | | 50.38 | 93.13 | 361 | Lansdowne Hous. | p | 52.14 | 87.53 | 256 |
| Pickle Lake | | 51.27 | 90.12 | 369 | Red Lake A | p | 51.04 | 93.49 | 386 |
| Winisk | | 55.16 | 85.07 | 12 | Cochrane | | 49.04 | 81.02 | 275 |
| Earlton A | | 47.42 | 79.51 | 243 | Fort Albany | | 52.13 | 81.40 | 15 |
| Haileybury | | 47.27 | 79.38 | 215 | Heaslip | | 47.48 | 79.50 | 222 |
| Iroquois Falls | | 48.45 | 80.40 | 259 | Island Falls | | 49.35 | 81.22 | 218 |
| Kapuskasing | p | 49.25 | 82.26 | 218 | Kapuskasing A | | 49.25 | 82.28 | 226 |
| Kirkland L. | | 48.09 | 80.02 | 320 | Montréal River | | 47.07 | 79.29 | 183 |
| Moosonee | p | 51.16 | 80.39 | 10 | New Liskeard | | 47.30 | 79.40 | 194 |
| Smoky Falls | | 50.04 | 82.10 | 183 | Timmins | p | 48.30 | 81.20 | 335 |
| Wawaitin | | 48.21 | 81.24 | 271 | | | | | |
| QUEBEC | | | | | | | | | |
| Abitibi Post | | 48.43 | 79.22 | 259 | Amos | p | 48.34 | 78.07 | 305 |
| Chapais | | 49.47 | 74.52 | 402 | Chapais 2 | | 49.47 | 74.52 | 396 |
| Chibougamau | | 49.55 | 74.22 | 378 | Fort George | | 53.50 | 79.00 | 7 |
| La Ferme | | 48.35 | 78.10 | 320 | La Sarre | | 48.48 | 79.12 | 274 |
| Mistassini P. | | 50.30 | 73.55 | 383 | Nitchequon | p | 53.12 | 70.54 | 515 |
| Senneterre | | 48.24 | 77.15 | 316 | Val d'Or | p | 48.04 | 77.47 | 337 |
| Inukjuak A | p | 58.27 | 78.07 | 20 | Kuujjuarapik | p | 55.17 | 77.46 | 14 |
| C. Hopes Adv. | | 61.05 | 69.33 | 73 | Kuujjuaq | p | 58.06 | 68.25 | 37 |
| Schefferville | | 54.48 | 66.49 | 522 | | | | | |

end, thus a positive thermal anomaly is induced. The Arctic Front is forced to a more southerly position until the end of December (Bryson and Hare, 1974). The late season is more homogeneous, with fewer local anomalies.

The 67 temperature and the 27 SLP series can be reduced to a few independent variables representing the basic structure of the meteorological networks using principal components (PC) analysis.

For each season, the (67x67) correlation matrix of the temperatures is transformed into eigenvalues and eigenvectors. The eigenvectors are in fact the components and the eigenvalues, in decreasing order, are the proportions of variance explained. The first four PC's explain approximatively 90% of the total variance for each season, except for the summer case where this is reduced to 82.5% (probably due to a larger variance concentrated in the smaller scales). The structure of the PC matrix is similar for the four seasons, while the relative importance of the components varies.

The first PC is called "facteur de taille" (Benzécri, 1973). This means that it represents the common variations of the network, when all correlations are positive (inducing same sign projections of the stations over this first PC). It is maximum for autumn, the most thermally homogeneous season. The second PC has a north-south gradient, the third has a pole in the east and the fourth in the west. The north-south contrast is maximum during Summer because of the Arctic Front. It is evident that main features of the climate of the Hudson Bay area are shown by this preliminary analysis.

The (27x27) correlation matrix of the sea-level pressure is transformed similarly. The first four PC's together explain from 83.7 % of the variance (summer) to 94.5% (winter). Here winter results are different because of larger scales of variations, however the same north-south and east-west gradients occur. The "facteur de taille" is weak for summer and absent for autumn. For these seasons, negative correlations are present between some eastern and western stations. This seems to be related to the position of the Arctic Front: a relatively small value of the sea level pressure in the north-east is related to a more northern trajectory of the front and thus to SLP with relatively large values in the South.

## 4. TRANSFER FUNCTIONS

The basis of the transfer function is a regression equation which is calibrated over a recent period where meteorological and proxy data are available. Then Equation 1 is applied to ancient proxy data so that an estimate of past climate is deduced:

$$y = \sum_{j=1}^{m} a_j x_j \qquad (1)$$

where y is a climatic parameter, the $x_j$ are the m proxy variables, and the $a_j$ are the corresponding regression coefficients. Here, the calibration period is set to 1925-1979 and the extrapolation is extended back to 1700. For each seasonal thermal parameter, a set of meteorological variables is defined by the first four principal components (see above) and the set of proxy data is composed of 16 historical series and 7 tree-ring series (Figure 2a to 2d).

The summer temperature is used to illustrate the method. Seventeen regressors are selected: (i) the 7 tree-ring series for their evident relation with the summer climate; (ii) the same 7 one-year lagged series because of the possible persistence of the climate effect on growth; (iii) the historical series CYSU of summer temperature in the Chuchill/York region; and (iv) the Winnipeg ice condition series, WINB and WINF, in order to introduce southern variables.

The PC's of these 17 regressors are computed. Thirteen are kept, using the PVP criterion (ie. the PC with a cumulative eigenvalues product larger than 1: Guiot, 1985a). A canonical analysis between these 13 PC's and the 4 climatic PC's is performed and an inverse transform enables one to deduce the regression coefficients between the four PC's and the 17 regressors (Blasing, 1978). The results (Table 4) show that the first PC has the best fit ($R^2$=0.67), and as it explains the largest part of the variance of the network (41.5%), it can be said that the main characteristic of the summer temperature is well restored. Table 4 also shows that the tree-ring series are best related to the summer temperature.

The next step is the application of the regression coefficients to the whole proxy series (1700-1979). This gives an extrapolation of the thermal PC which must be retransformed to the original series. Arbitrarily, six stations are selected to represent the network and the associated proxy series: (i) Churchill, northern Manitoba; (ii) Red Lake, western Ontario; (iii) Moosonee, northern Ontario; (iv) Kuujjuarapik, central Quebec; (v) Kuujjuaq, northern Quebec; (vi) Nottingham Island, southern NWT. Table 5 shows the loading factors of the six stations on the four PC's. These loading factors, are, in fact, the weighted averages (in inverse function of the distance) of the loading factors of the neighbouring stations, used to improve the regional representativeness. They specify the retransformation back to the selected stations. The goodness of fit can be checked for 1925-1973 by the curves presented in Figure 3c: the worst disagreeements are found for Kuujjuarapik, but generally, the fit appears good.

It is necessary to check the stability of the reconstructions by using series starting before 1925. Raw data (before estimating the missing data) are used. First, the correlations between the reconstructions and the actual values for the six stations are given by Figure 4. These correlations (their average is 0.54), with degrees of freedom ranging from 30 to 40, are all significant at the 0.01-level, except for Nottingham (R=0.24). Nevertheless the reconstruction for Nottingham Island is significantly correlated with the actual values of Churchill (R=0.61), but since there are no available proxy data at this site, further explanations of its climatic peculiarities are not offered. For an independent verifi-

TABLE 4. Standardised regression coefficients (multiplied by 10) of the 4 PC versus the proxy variables for the 4 seasons.

| variable | time | WINTER 1 2 3 4 | SPRING 1 2 3 4 | SUMMER 1 2 3 4 | AUTUMN 1 2 3 4 |
|---|---|---|---|---|---|
| Churchill 1 | t | | | | –1 –2 –1 –0 |
| Churchill 3 | t | | | | –1 +1 +2 +1 |
| Churchill 5 | t | –1 +1 +0 +1 | +0 +0 –0 –1 | | |
| York 1 | t | | | | –1 –0 +1 –0 |
| York 3 | t | | | | +0 +3 +1 +2 |
| York 5 | t | +0 +2 –0 –0 | –1 –1 –0 –1 | | |
| Moosonee 1 | t | | | | –3 +1 –2 –2 |
| Moosonee 3 | t | | | | –1 –1 –1 +1 |
| Moosonee 5 | t | +0 +1 –0 –1 | +0 +0 +2 –2 | | |
| Winnipeg fr. | t | | | +2 +0 +0 +2 | +2 +3 +1 +0 |
| Winnipeg br. | t | –3 –1 –2 –0 | +2 +0 +3 –3 | +2 –3 –1 –2 | |
| Ch/York Win. | t | –7 –3 +0 –4 | | | |
| Ch/York Spr. | t | | –6 +2 –1 –6 | | |
| Ch/York Sum. | t | | | –3 –1 –0 –2 | |
| Ch/York Aut. | t | | | | –2 –0 +0 +0 |
| Bord. Beacon | t | 0 +5 1 +2 | +0 –3 2 +0 | +1 1 2 +2 | +0 1 +0 +1 |
| Fort Chimo | t | +0 –1 +0 –1 | –0 +3 +1 +2 | –2 –0 –1 +2 | +0 +0 +2 –1 |
| Cri L. RW. | t | –0 +1 –2 –0 | –1 –2 +1 –0 | –3 –3 +2 –1 | –1 +1 –2 +1 |
| Cri L. dens. | t | –0 +3 +2 –1 | –1 +1 +2 +0 | –3 –3 +2 +0 | –2 –3 –3 +3 |
| Nain | t | +3 –2 +2 –2 | +3 –2 +0 –1 | +3 –0 –0 +1 | +2 +2 –0 +0 |
| Chur. O.F. | t | –2 –1 –0 +2 | –0 +0 +1 +2 | +0 –0 –0 –2 | –1 –0 –0 –1 |
| Chur. F.T. | t | +3 –1 +2 –2 | +1 –2 +2 –1 | +3 –0 +1 –1 | +3 –0 –0 +3 |
| Bord. Beacon | t+1 | | +2 –1 +2 +0 | –0 –1 –1 +0 | +2 +2 +1 –0 |
| Fort Chimo | t+1 | | –2 +0 +1 +3 | –0 +1 –0 +1 | –3 –1 –2 –2 |
| Cri L. RW. | t+1 | | –2 –1 +3 –2 | +2 +0 +3 +2 | +0 +1 –3 –1 |
| Cri L. dens. | t+1 | | +2 +1 –0 –2 | –1 +1 –0 –1 | –0 +1 +2 –1 |
| Nain | t+1 | | –0 +1 +1 –1 | +4+0 +0 +0 | +1 –2 –2 +2 |
| Chur. O.F. | t+1 | | –1 +1 +0 +0 | –0 –2 –1 –0 | –2 –1 –1 –0 |
| Chur. F.T. | t+1 | | +1 –2 +0 –0 | +1 –3 +1 +1 | +1 +2 –0 +2 |
| Churchill 1 | t–1 | +1 +0 –0 –1 | | | |
| Churchill 3 | t–1 | +0 +0 +1 –0 | | | |
| York 1 | t–1 | +1 +0 –1 –1 | | | |
| York 3 | t–1 | –2 –1 +2 +3 | | | |
| Moosonee 1 | t–1 | –1 –0 –2 +3 | | | |
| Moosonee 3 | t–1 | –1 –1 –2 –2 | | | |
| Winnipeg fr. | t–1 | +1 +1 –0 –2 | | | |
| determ. coeff. | | 65 37 44 43 | 57 34 53 59 | 67 49 42 27 | 72 46 53 39 |
| F-value | | 5. 2. 2. 2. | 3. 1. 3. 4. | 6. 3. 2. 1. | 6. 2. 3. 2. |

FIGURE 2a) Winter Temperature

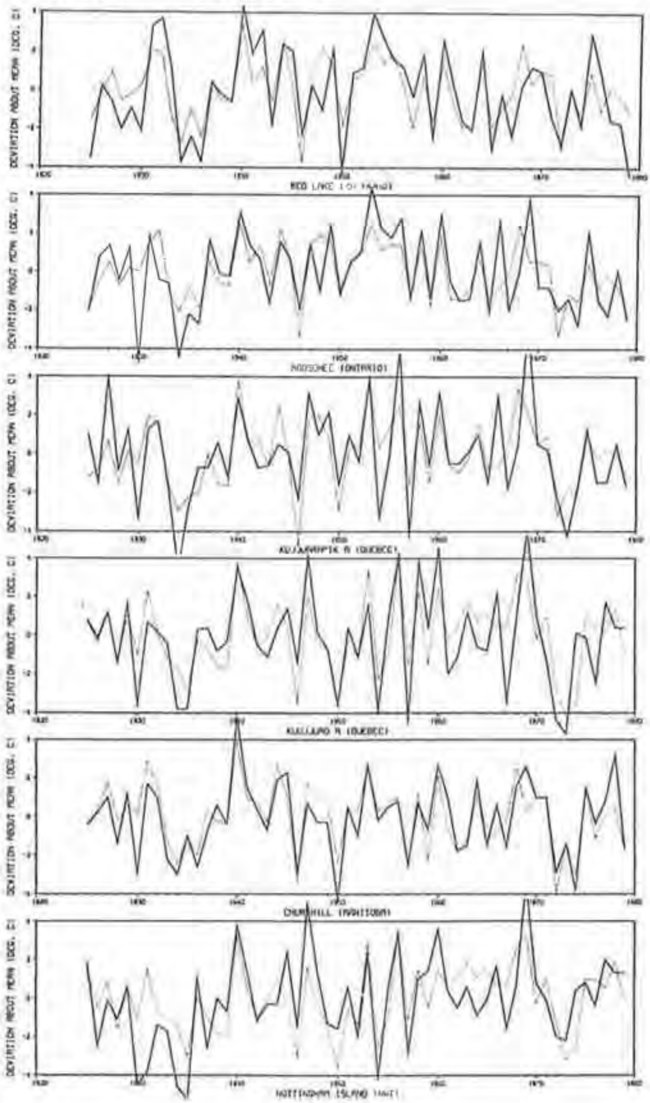


FIGURE 3. Calibration of the seasonal temperature in six stations: the dotted lines are the estimates and the undotted lines are the actual observations. Solid lines represent the filtered series (the cut-off period of the filter is 7 years).

FIGURE 2b) Spring Temperature

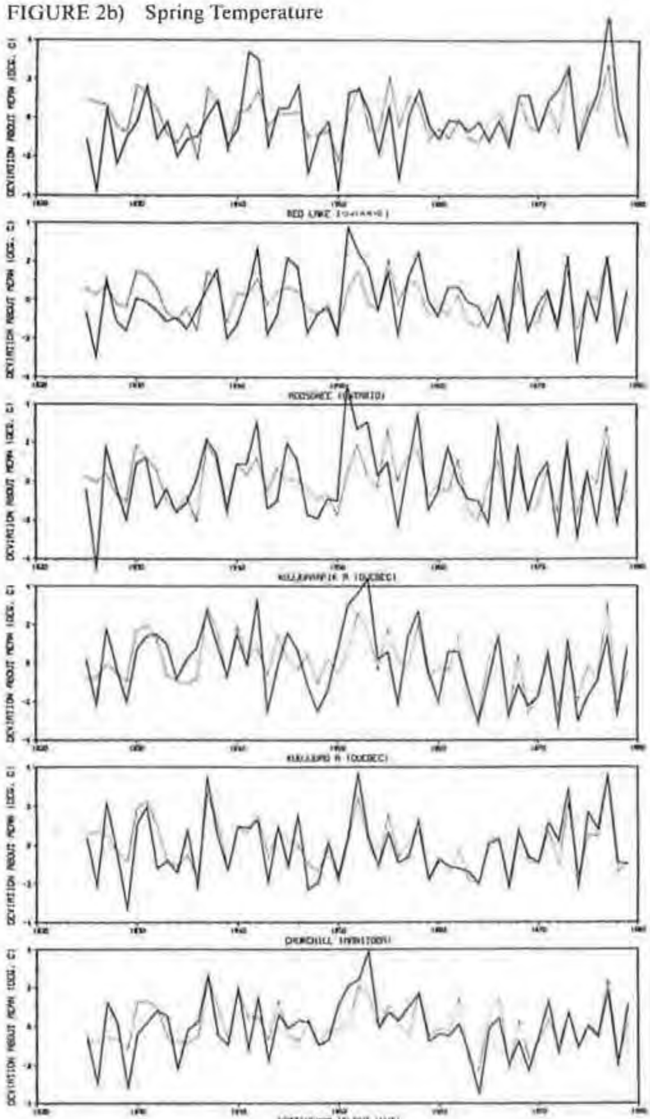


FIGURE 2c) Summer Temperature

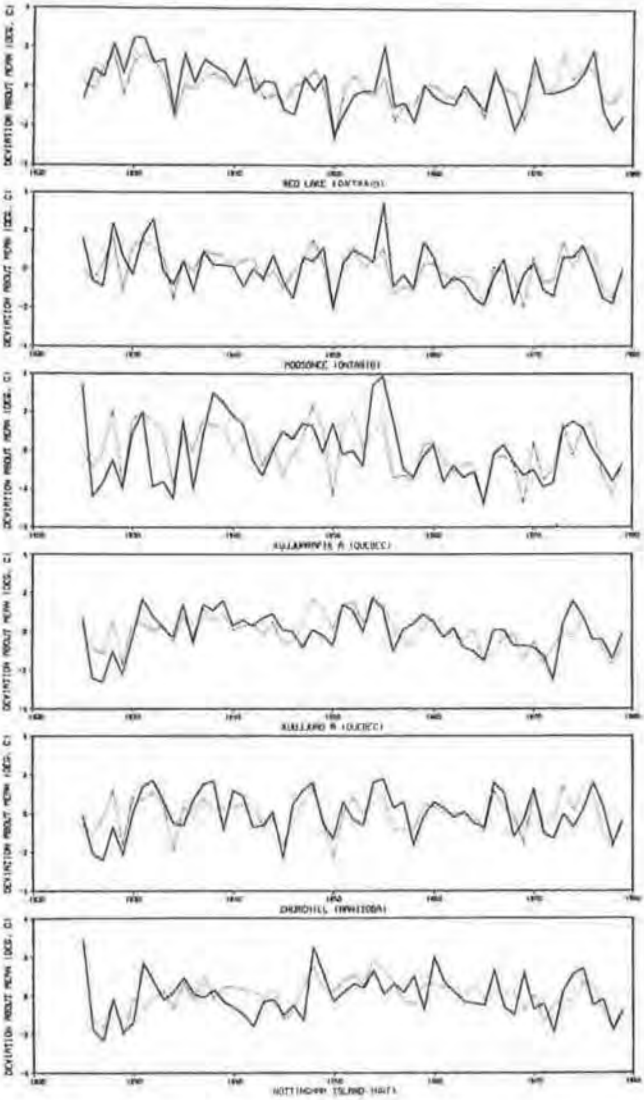


FIGURE 2d) Autumn Temperature

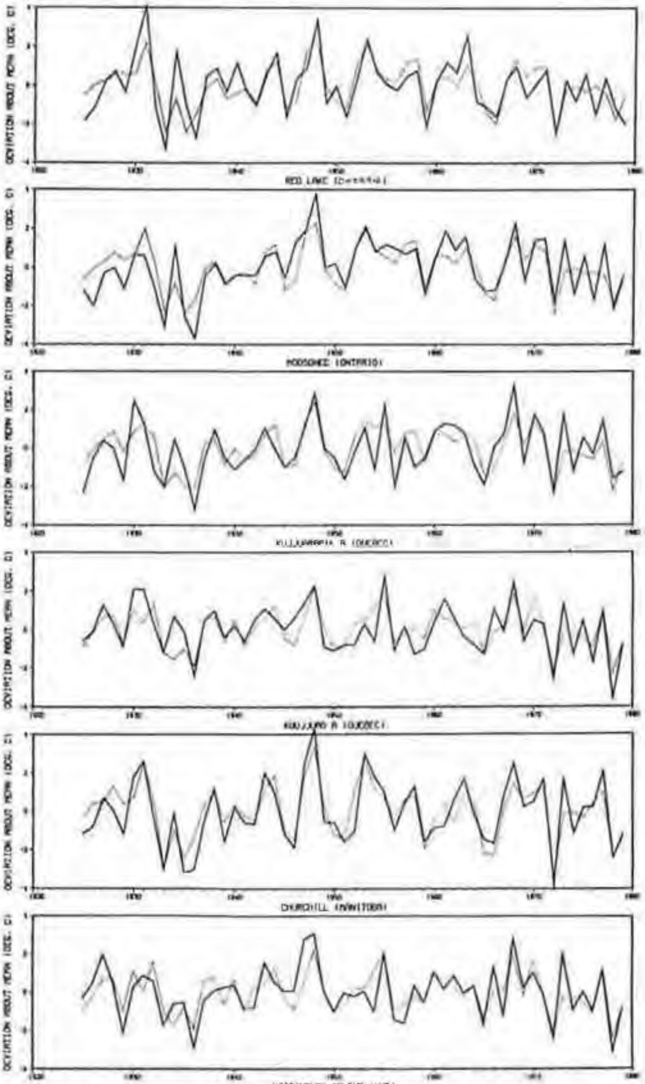


TABLE 5 Loading factors of the 6 stations vs. the 4 PC for 4 seasons; these are the eigenvectors (averaged on a regional basis) multiplied by the standard deviation of the corresponding PC and by this of the corresponding station, so that the reconstructions are in °C.

| | | Red L. | Moos. | Kuujjar. | Kujjuaq | Church. | Nottingham |
|---|---|---|---|---|---|---|---|
| Winter:PC | 1 | −1.79 | −1.85 | −2.26 | −1.79 | −1.86 | −1.27 |
| | 2 | .90 | .69 | .28 | −1.53 | .00 | −1.52 |
| | 3 | .24 | .23 | −.57 | −.77 | .46 | −1.27 |
| | 4 | −.45 | .23 | .00 | .26 | −.46 | .00 |
| Spring:PC | 1 | −1.47 | −1.38 | −1.79 | −1.58 | −1.54 | −1.13 |
| | 2 | −.74 | −.31 | −.55 | .79 | .00 | .64 |
| | 3 | −.37 | −.15 | .22 | .59 | −.39 | .64 |
| | 4 | −.18 | .15 | .00 | .00 | −.39 | −.32 |
| Summer:PC | 1 | −1.05 | −1.12 | −1.54 | −.58 | −.98 | −.28 |
| | 2 | .15 | −.14 | −.22 | −.63 | −.41 | −.84 |
| | 3 | .60 | .14 | −.22 | −.63 | .27 | −.56 |
| | 4 | .00 | .00 | .00 | .25 | −.41 | −.28 |
| Autumn:PC | 1 | −1.34 | −1.38 | −1.35 | −1.12 | −1.58 | −1.08 |
| | 2 | .50 | .46 | .15 | −.42 | .20 | −.62 |
| | 3 | .17 | .00 | −.15 | −.28 | .60 | −.31 |
| | 4 | −.17 | −.15 | .15 | .28 | .20 | .31 |

cation, it is necessary. sometimes to use distant stations. Nevertheless, the intercorrelations are sufficiently high so that large scale climatic variations can be analyzed. Data from three meteorological stations are available: (i) Fort Hope (Ontario), with 17 years of valid observation in the 1891-1930 interval; (ii) Moose Factory (Ontario), with 48 observations in the 1877-1938 interval; (iii) York Factory (Manitoba), with 42 observations in the 1714-1870 interval. The first two can be used to check the reconstruction of Red Lake, the second for Moosonee and Kuujjuarapik, and the third for the others. The correlations are presented in Figure 4. Their average is, 0.42, which is close to the fit over the dependent period: the reconstructions are thus stable in spite of a relatively modest fit. A last signal check is given by computing the correlations with the longest series: (i) Norway House, Manitoba, with 38 observations between 1885 and 1968; (ii) Cochrane, Ontario, with 63 observations between 1910 and 1979; (iii) Mistassini, Québec, with 55 observations between 1885 and 1980. It is clear (Figure 4) that these are also significant ($R \cong 0.50$).

The same procedure is applied to the other three seasons. As presented for summer, Table 4 shows the regression coefficients, Figure 3 shows the accuracy of the fit and Figure 4 the verification correlations. It is clear that these seasons are better reconstructed than summer. As tree-ring series are more related to summer temperature and ice condition series are more related to other seasons, this better fit demonstrates that historical series have clearer linkage with climate than tree-ring series. The correlations with actual values over the calibration interval are larger than 0.70 and close to 0.50

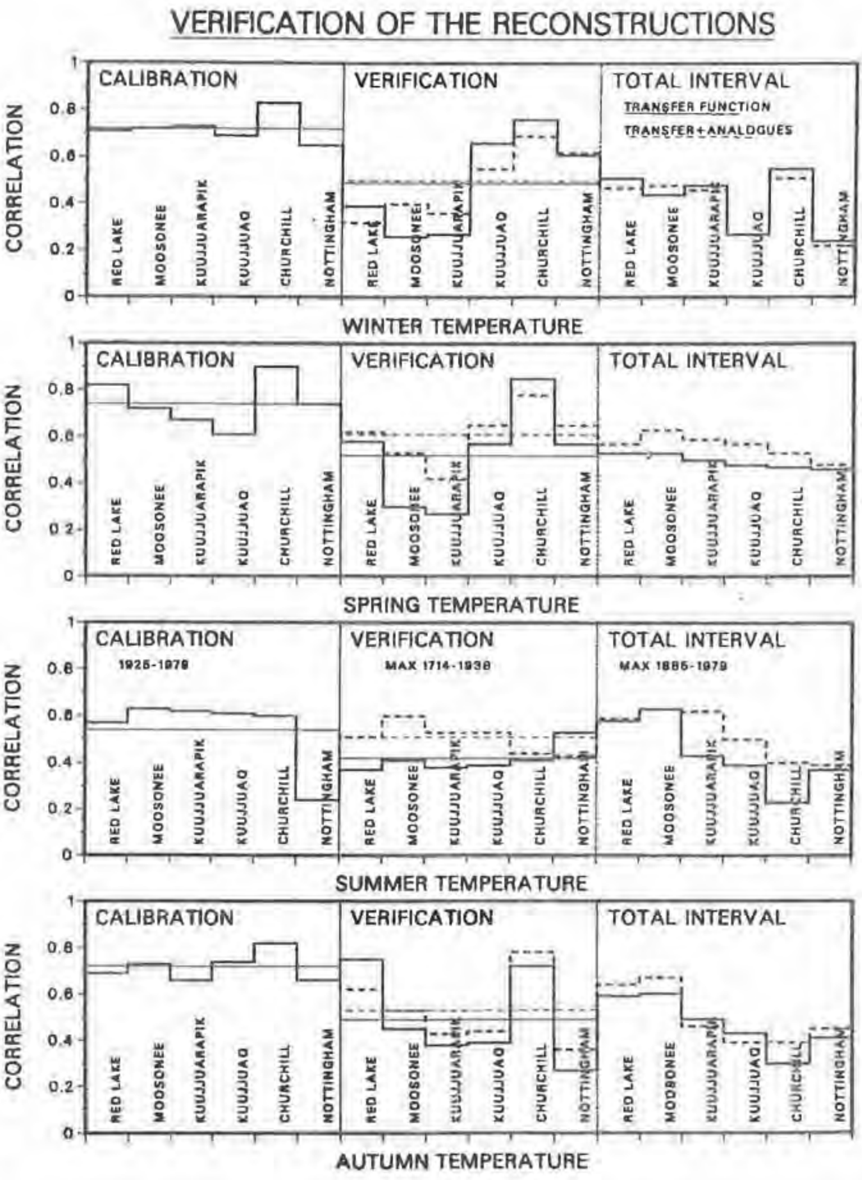



FIGURE 4. Correlation coefficients between the reconstructions and the actual observations. These are computed, over the 1925-1979 calibration interval, for the six selected stations; over various intervals extending maximum over 1714-1938, for three other stations (Fort Hope, Ont., Moose Factory, Ont., York Factory, Man.); and over various intervals extending maximum over 1885-1979, for three other stations (Norway House, Man., Cochrane, Ont., Mistassini, Qué.).

over the independent interval. Finally, six series, for four seasons, are available. Six annual series are produced by averaging the four seasons.

This kind of verification is not adequate to check the reliability of the trend, because the reference series are too short. The historical series of annual temperature, given by Ball and Kingsley (1984), will be used to verify the goodness of fit of the trend for our reconstruction of Churchill's annual temperature. Six periods are defined according to the availability of the data (Table 6). Both series are compared to their mean and the anomalies are computed for the six periods. The evident discrepancy shows that the trend is not well reproduced. This conclusion can probably be extended to other reconstructions. Some procedures for improvement will be examined below. Only the final reconstructions will be presented in Figure 5.

## 5. ANALOGUE METHOD

In the preceeding section, the transfer function enabled one to fit very well the interannual variations, but not the trend. Essentially, the transfer function, which extrapolates the information contained in the reference set, is dominated by the higher frequencies, which control the fitting criterion and finally the extrapolation. An alternative method is now proposed which was also used by Alt (1983), but in a qualitative way. The current data, between 1925 and 1979, are considered as a reference set which contains all possible scenarios of the climate between 1700 and 1924. So, for each year from 1700-1924, an analogue is searched for in the period 1925-1979. The selected scenario is considered as a "model" for the historic year. With this method, it is not possible to obtain a more extreme yearly climate than those which are represented in the reference set; only frequent cold years can be responsible for a colder mean climate than those included in the reference years. The results will show a posteriori that the 1925-1979 period is sufficiently exhaustive.

TABLE 6 Mean anomalies of the annual temperature (to the 1925-1979 normals) in York Factory (actual values) and in Churchill (estimates) for different periods when historical data are available. The normal at York is evaluated to -7.3°C and at Churchill to -6.7°C. The first reconstruction (FT) is given by transfer function and the second one (FT+A) is given by transfer function + analogues method.

| period | no. obs | York Factory | Chur. FT | Chur. FT+A |
|---|---|---|---|---|
| 1775-1797 | 10 | −0.24 | +0.65 | −0.19 |
| 1815-1826 | 12 | −0.04 | −0.47 | −0.50 |
| 1827-1832 | 6 | +1.15 | −0.15 | −0.05 |
| 1838-1852 | 15 | +0.02 | +0.38 | +0.10 |
| 1875-1889 | 15 | −0.77 | −0.26 | −0.33 |
| 1899-1910 | 12 | −0.13 | +0.27 | +0.07 |
| 1775-1910 | 70 | −0.13 | +0.07 | −0.16 |

a) winter (°C)

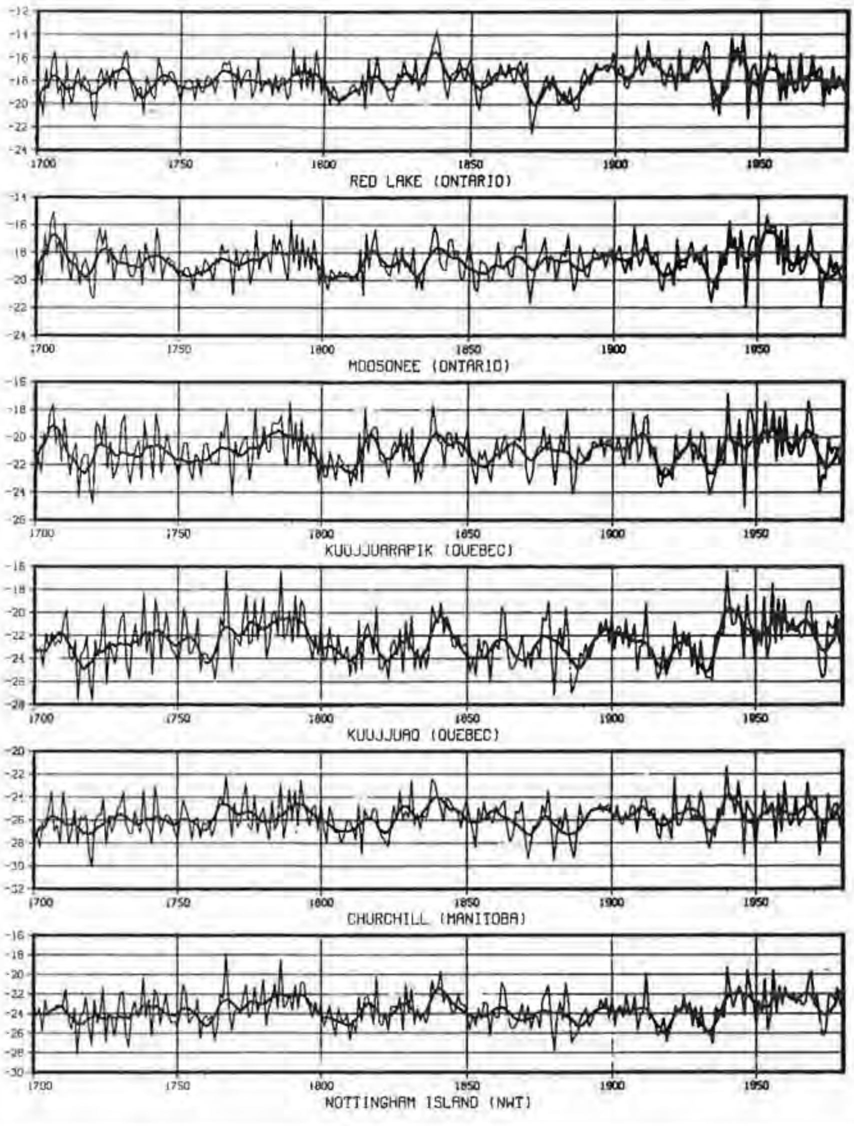
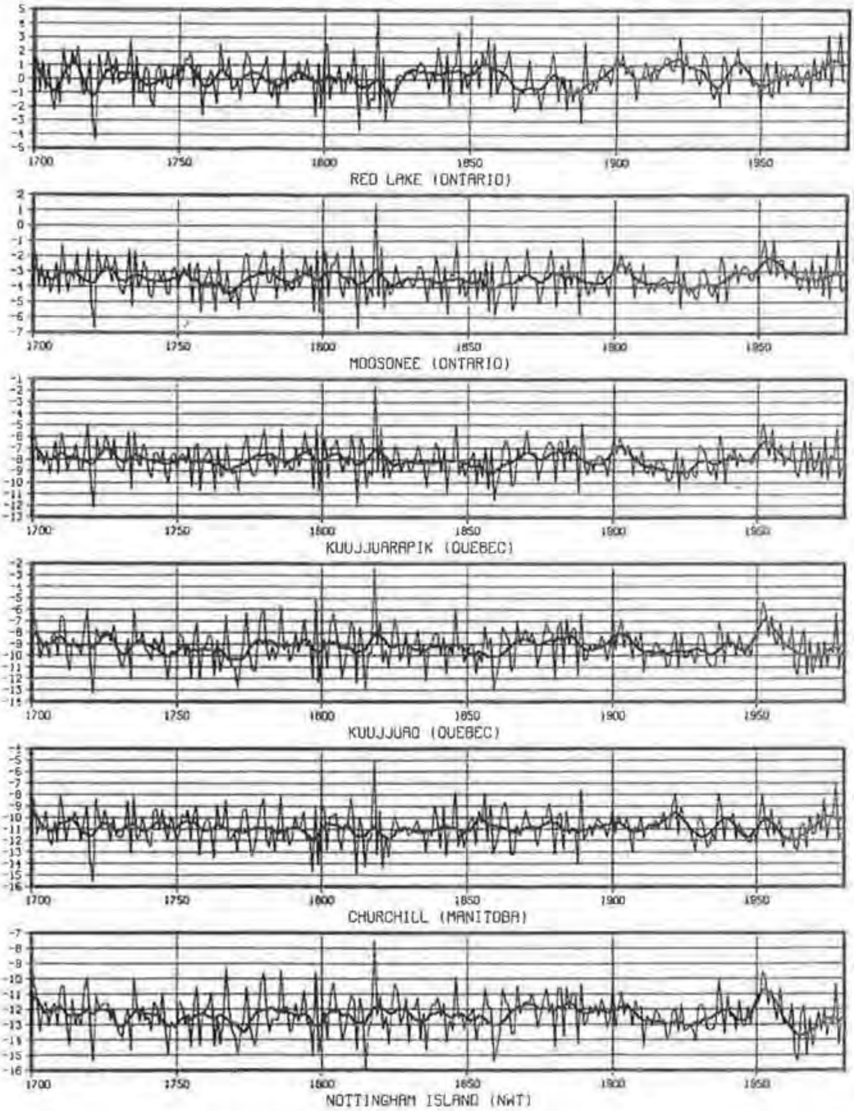
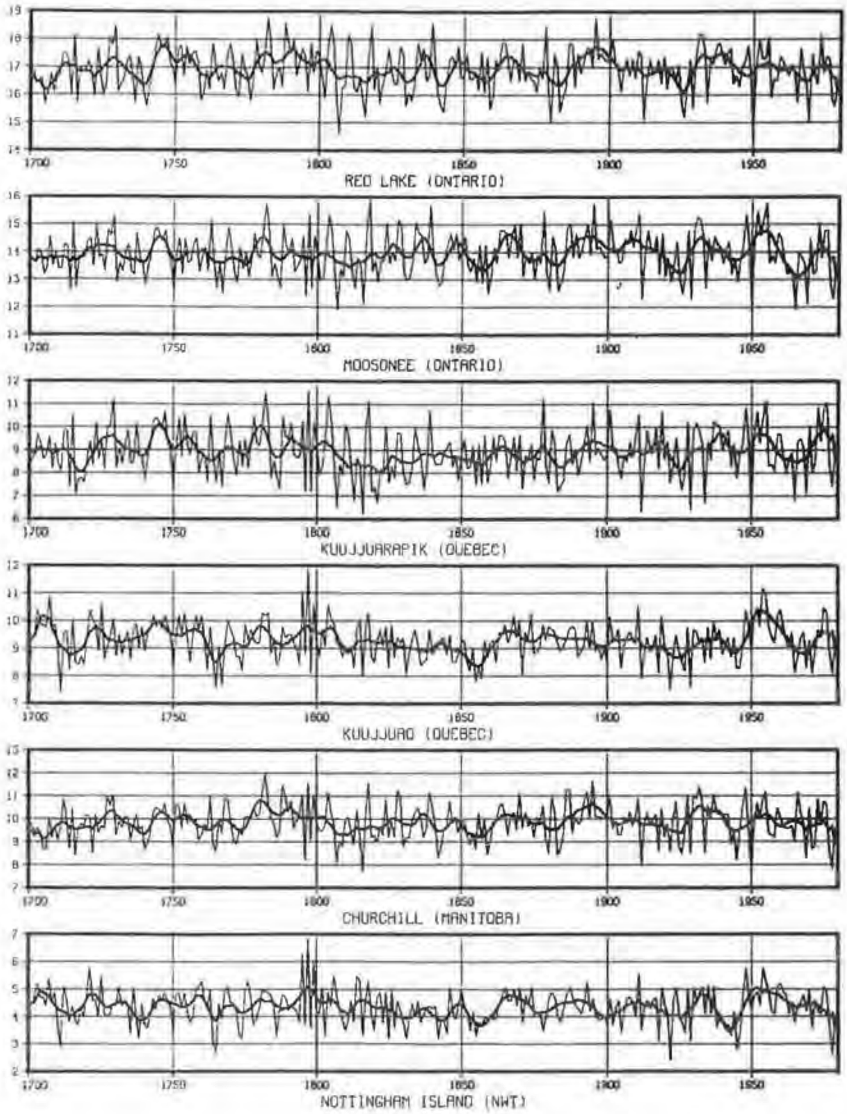



FIGURE 5. Reconstructions of the seasonal temperatures for six selected stations; the darker lines represent the temperatures smoothed by a digital filter (cut-off period = 7 years).

b) spring (°C)

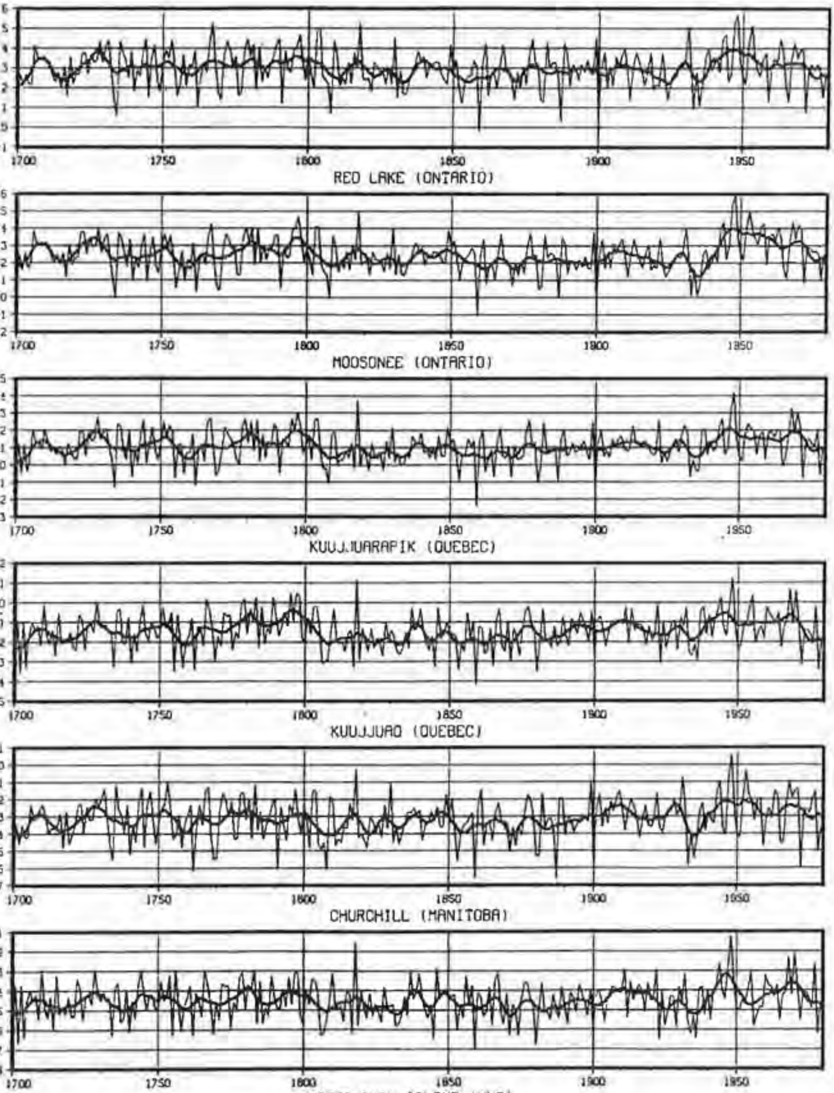

RED LAKE (ONTARIO)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

c) summer (°C)

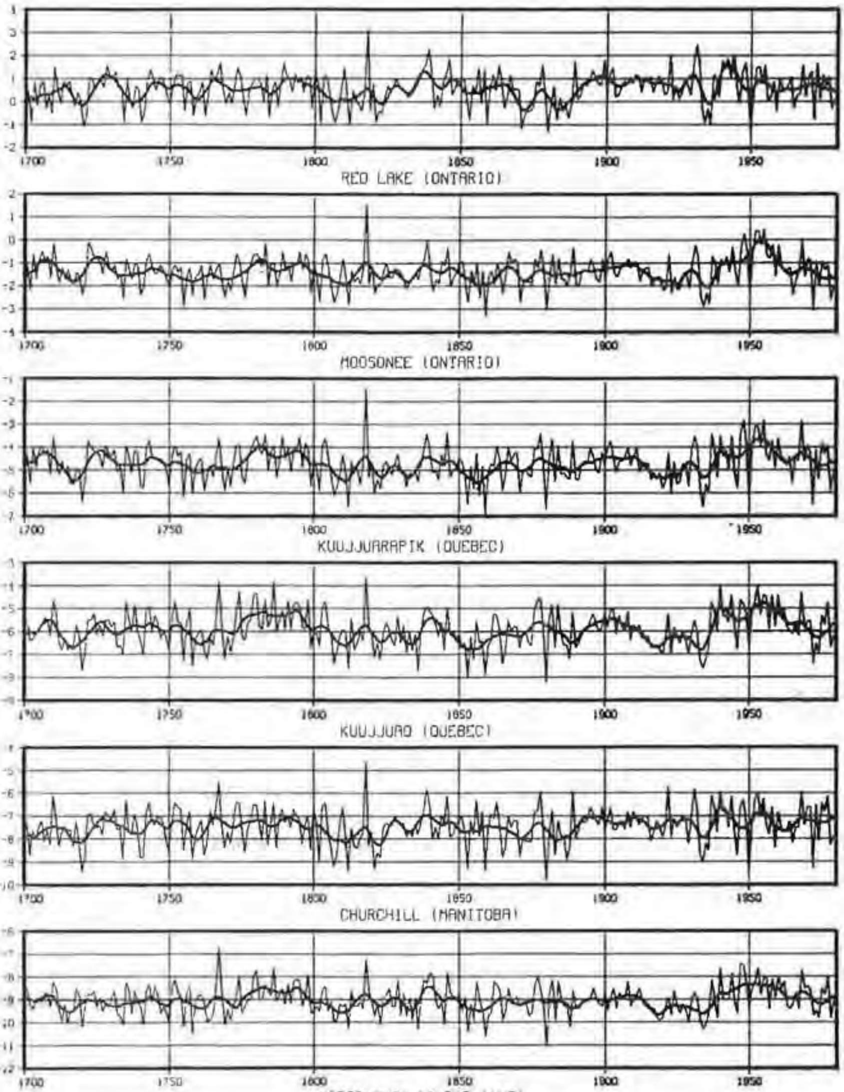


RED LAKE (ONTARIO)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

d) autumn (°C)


RED LAKE (ONTARIO)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

e) annual (°C)



1700
1750
1800
1850
1900
1950
RED LAKE (ONTARIO)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

In order to achieve the best application of this method, it is necessary to carefully choose the defining criteria of the analogue. The eleven ice condition series and the seven tree-ring series have appeared exhaustive in the preceeding section. These 18 variables are transformed into 13 principal components, selected by the PVP criterion, as seen in the preceding section, in order to reduce the redundancy and the noise. Nevertheless all of these variables are not equally important in representing the temperatures of the region. Canonical analysis may be used to define the linear combination of the proxy series which is the most correlated with the temperatures.

The 4 PC's of the four seasonal temperatures are used as the dependent set, so that the complete thermal field is considered simulaneously. In order to emphasize the trend and because the tree-ring series are often autocorrelated, the 16 climatic PC's are time-filtered as follows:

$$y_i^f = 0.25\, y_{i-1} + 0.50\, y_i + 0.25\, y_{i+1} \qquad (2)$$

where the index f indicates the filtering. This filter has a response of less than 50 % for frequencies larger than ¼. Finally two groups with a similar frequency behaviour are defined: (I) the 13 PC's of the 18 proxy data sets and (II) the 16 PC's of the filtered seasonal temperatures. A canonical analysis (for details see Clark, 1975) was performed on the 1925-1979 interval. The first 9 canonical axes are significant (0.05 level) according to a chi-squared criterion. These are computed, for the proxy variables, over the 1700-1979 interval. The resulting (280 × 9) matrix is used to define the analogues. These have the characteristic to best represent the temperatures. Now it is necessary to define a proximity measurement. The year k from the 1925-1979 interval is said to be the best analogue of the year i from the 1700-1924 if:

$$d(i,k) = \sum_{j=1}^{9} (x_{ij} - x_{kj})^2 \text{ is minimum} \qquad (3)$$

where $x_{ij}$ is the value of the jth canonical component for the year i. For every year i, the best analogue (k) is found and the thermal regime of year k is assigned to i, i.e. the mean temperature of the four seasons.

By using a 7-weights low-pass filter (the same as used for smoothing the reconstructions of Figure 5), the low frequencies of the series reconstructed by the analogue method are retained and those of the series reconstructed by the transfer function are removed. The resulting series are summed and the final reconstructions are depicted in Figure 5.

Figure 4 enables the evaluation of improvements obtained by the coupling of both methods. It is clearly better for spring and summer (mean correlation increases, respectively, from 0.52 to 0.61 and from 0.42 to 0.51), modestly better for autumn (from 0.49 to 0.53), and negligible for winter. Table 6 shows that the trend is now well reconstructed since the anomaly of the period 1775-1910 is estimated to -0.16°C, which compares favourable to the actual -0.13°C.

An initial observation is that the sea-level pressures are not independent of the temperatures (Table 7), but that the linkage is complex.

The proxy data available do not allow a direct reconstruction of the total pressure variation, but only those parts which are related to the temperature field. A regression is computed between the selected 16 PC's of the pressure field and the 30 temperature series (6 selected stations for reconstruction × 4 seasons / annual mean) over the common 1953-1983 interval. The regression coefficients are then applied to the reconstructed temperature series from 1700 to 1979. A (280 × 16) matrix is so developed, that will define the analogues. Finally the seasonal SLP series for the 6 selected stations are reconstructed by using relationship (2) with this (280 × 16) matrix (Figure 6). Table 8 shows a first trial. Generally, Thompson (THOM) and Nottingham Island (NOTT) provide the most stable reconstructions and the best reconstructed seasons are winter and autumn. Nevertheless, this is not a proof of validity, because the correlations between both fields are not perfect.

A second possibility of verification lies in a comparison with the reconstructions by Fritts *et al* (1971) for North America, Atlantic and Pacific Oceans. For Hudson Bay, these authors found winter anomalies of -2 mb in 1731-1735, 0 to 2 mb in 1791-1795 and 1811-1815 and finally 2 to 6 mb in 1890. Figure 6 confirms all except for the 1811-1815 series. The end of the 19th century and the beginning of the 20th are characterized by annual mean high pressures, while the 80 previous years are designated by low pressures, which appear also in the reconstructions of Fritts *et al*. This is encouraging and will be discussed below.

## 7. TREND ANALYSIS

The 1700-1979 interval can be divided into eight 35-year intervals, which is close to the standard normal period for climatological data (the standard number 30 is not chosen because it does not divide 280). The reconstructed temperatures and SLP are averaged for each 35-year interval by steps of 17.5 years.

In winter (Figure 7a), two temperature maxima appear 1) at the end of the 18th century and 2) the middle 20th century in the East, and,

TABLE 7 Multiple correlations between the PC of the SLP and those of the temperature.

| PC SLP | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|
| 1 | 0.76 | 0.85 | 0.75 | 0.79 |
| 2 | 0.75 | 0.88 | 0.85 | 0.82 |
| 3 | 0.88 | 0.78 | 0.75 | 0.84 |
| 4 | 0.75 | 0.82 | 0.72 | 0.84 |
| total | 0.77 | 0.85 | 0.79 | 0.81 |

a) winter (mb)

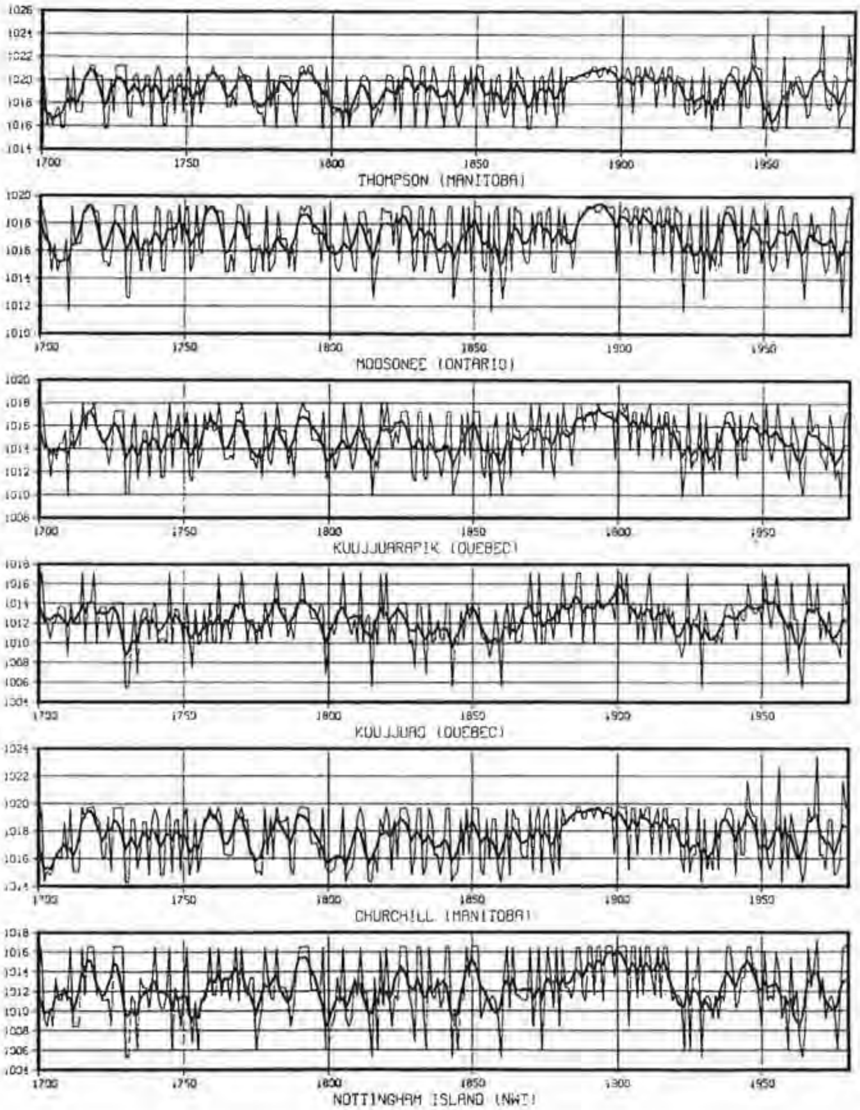
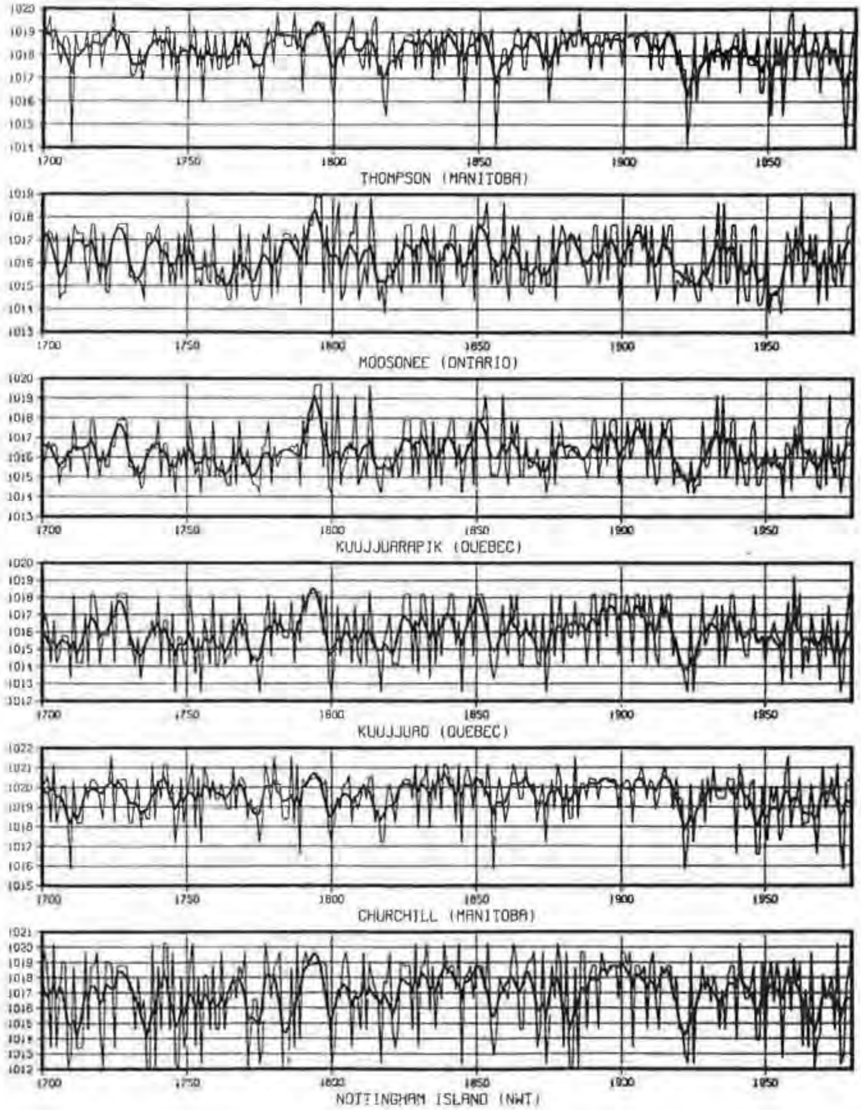


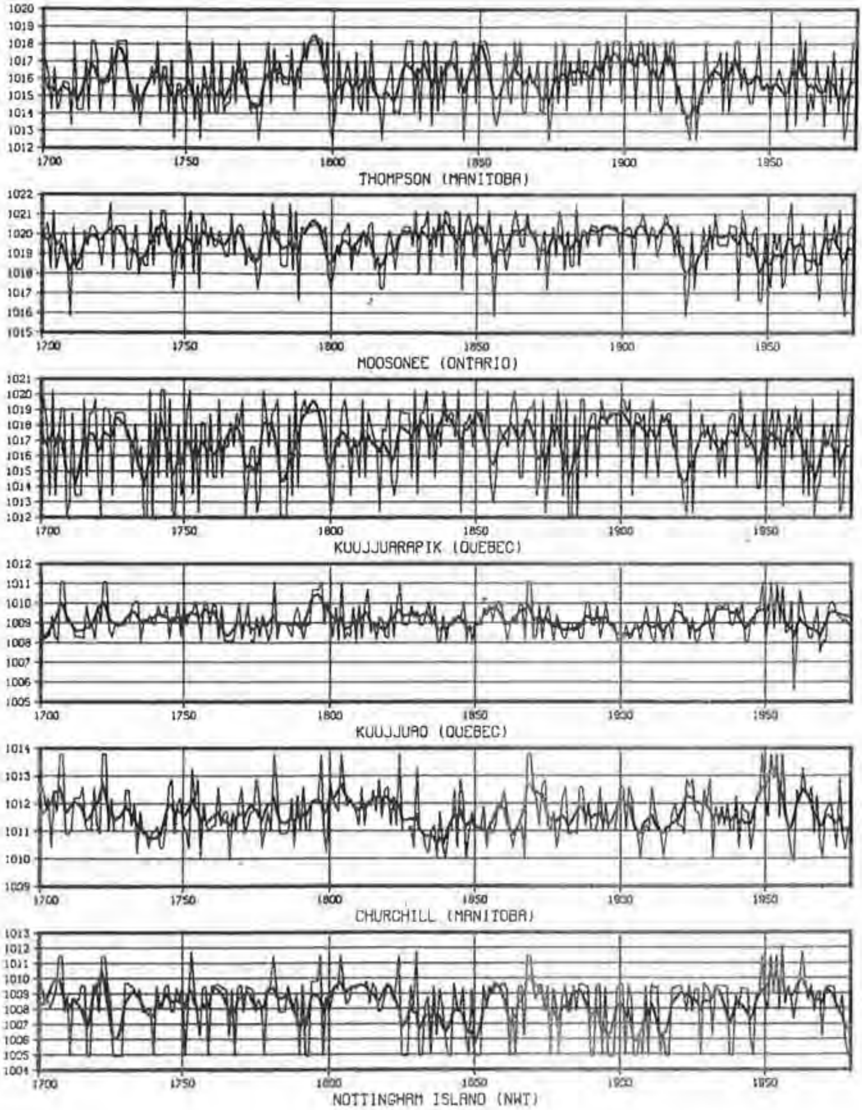

FIGURE 6. Reconstructions of the seasonal sea-level pressures for six selected stations; the darker lines represent the SLP smoothed by a digital filter (cut-off period = 7 years).

b) spring (mb)

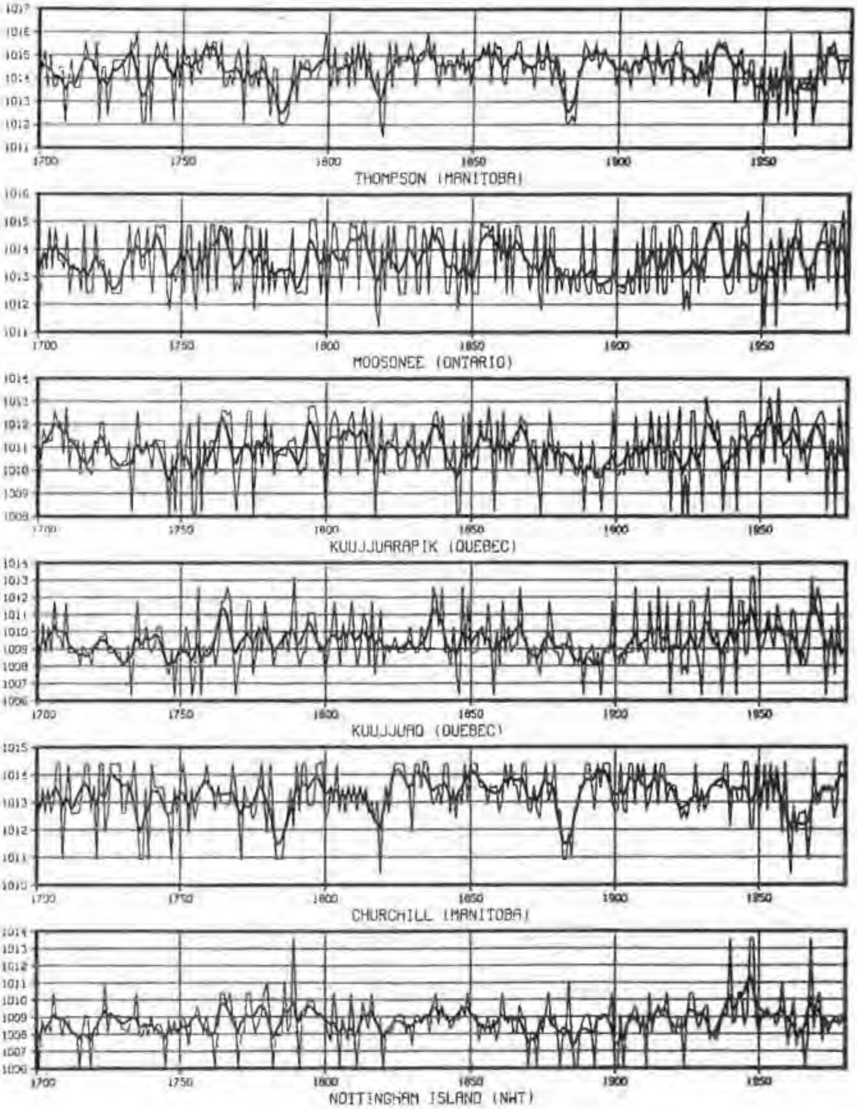


THOMPSON (MANITOBA)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

c) summer (mb)


THOMPSON (MANITOBA)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

d) autumn (mb)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MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

e) annual (mb)

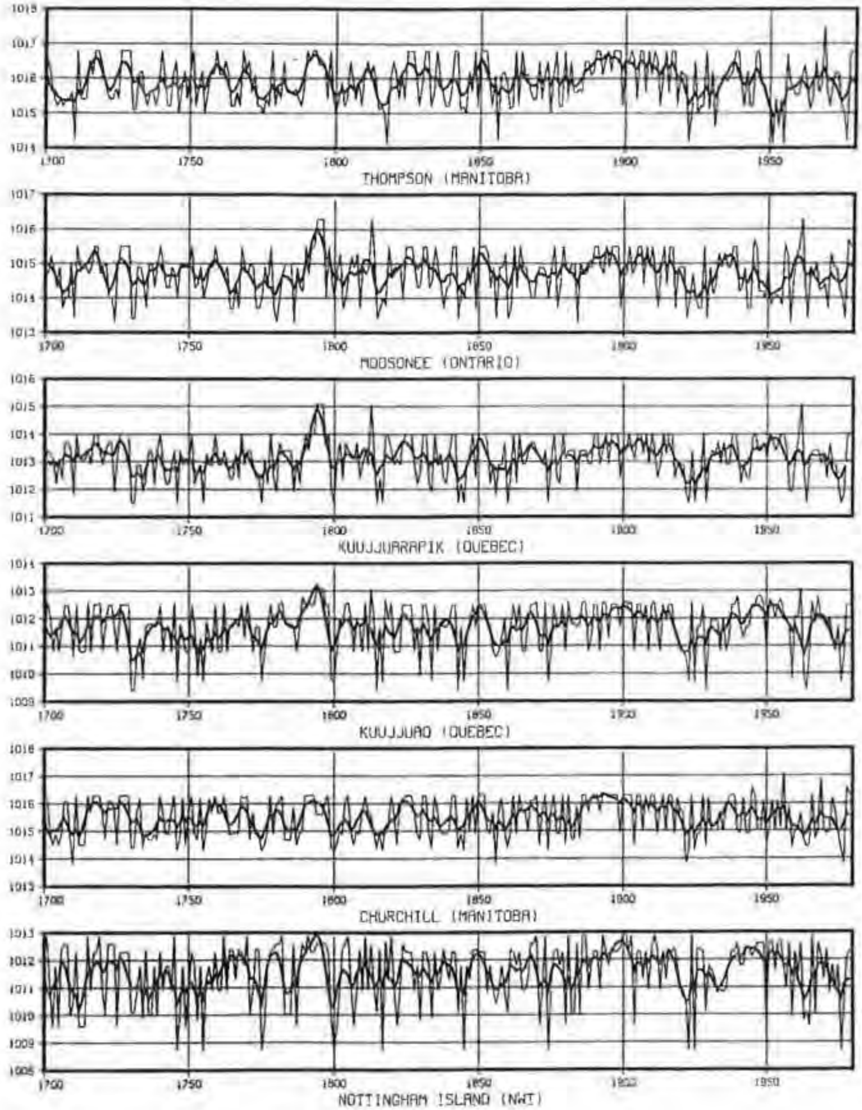

THOMPSON (MANITOBA)
MOOSONEE (ONTARIO)
KUUJJUARAPIK (QUEBEC)
KUUJJUAQ (QUEBEC)
CHURCHILL (MANITOBA)
NOTTINGHAM ISLAND (NWT)

TABLE 8 Verification of the stability of the correlation between reconstructed SLP and actual temperatures. The stations are represented by the first four letters except KUUJ = Kuujjuarapik, KUUA = Kuujjuaq, MOOF = Moose Factory, ndf = number of degrees of freedom. Only the parameters with at least a significant correlation are presented.

| actual P/actual T | | reconstructed Pressure | | | | actual Temperature | | | |
|---|---|---|---|---|---|---|---|---|---|
| (1953-1983) ndf = 31 | | stat. | period | corr. | ndf | stat. | period | corr. | ndf |
| *** WINTER *** | | | | | | | | | |
| THOM/NOTT | 0.46 | /NOTT | 1923-1970 | 0.47 | 42 | /HOPE | 1891-1930 | 0.41 | 19 |
| KUUA/MOOS | 0.35 | /MOOS | 1932-1979 | 0.35 | 45 | /HOPE | 1891-1930 | 0.22 | 19 |
| CHUR/NOTT | 0.42 | /NOTT | 1923-1970 | 0.47 | 42 | /HOPE | 1891-1930 | 0.40 | 19 |
| NOTT/NOTT | 0.38 | /NOTT | 1923-1970 | 0.40 | 42 | /HOPE | 1891-1930 | 0.23 | 19 |
| *** SPRING *** | | | | | | | | | |
| THOM/REDL | -.50 | /REDL | 1930-1979 | -.38 | 23 | /HOPE | 1891-1930 | -.11 | 19 |
| KUUA/KUUJ | 0.34 | /KUUJ | 1925-1979 | 0.28 | 45 | /MOOF | 1877-1938 | 0.21 | 43 |
| CHUR/REDL | -.33 | /REDL | 1930-1979 | -.09 | 23 | | | | |
| NOTT/KUUJ | 0.40 | /KUJJ | 1925-1979 | 0.43 | 45 | /MOOF | 1877-1938 | 0.35 | 43 |
| *** SUMMER *** | | | | | | | | | |
| THOM/MOOS | -.51 | /NORW | 1885-1968 | -.28 | 38 | | | | |
| MOOS/NOTT | -.38 | /NOTT | 1923-1970 | -.15 | 40 | | | | |
| KUUJ/CHUR | 0.34 | /YORK | 1714-1870 | 0.27 | 42 | | | | |
| KUUA/NOTT | -.27 | /NOTT | 1923-1970 | -.22 | 40 | /NORW | 1885-1968 | 0.43 | 38 |
| NOTT/NOTT | 0.33 | /NOTT | 1923-1970 | 0.17 | 40 | | | | |
| *** AUTUMN *** | | | | | | | | | |
| THOM/KUUA | -.41 | /NOTT | 1923-1970 | -.41 | 42 | | | | |
| MOOS/NOTT | -.35 | /NOTT | 1923-1970 | -.33 | 42 | | | | |
| KUUJ/REDL | 0.50 | /REDL | 1930-1979 | 0.29 | 26 | | | | |
| KUUA/REDL | 0.58 | /YORK | 1714-1870 | 0.20 | 42 | | | | |
| CHUR/KUUJ | -.39 | /NOTT | 1923-1970 | -.28 | 42 | | | | |
| NOTT/CHUR | 0.61 | /YORK | 1714-1870 | 0.51 | 43 | | | | |

around 1840 and slightly earlier (1910-1945), in the West. Between these maxima, the winters were cold, mainly in the East. For the SLP, the important peak in 1875-1910 has no thermal correspondence. It is possible to summarize the zonality of the atmospheric circulation by the difference between the two points of extreme latitude, Moosonee and Nottingham, and its meridional character by the difference between two points of extreme longitude, Thompson and Kuujjuaq. The warm periods in the East and South-East (late 18th century and 20th century) were characterized by a weak meridional circulation. The maxima in the West were marked by a weak zonal and strong meridional circulation. The Little Ice Age, finally, has been depicted by winters with strong meridional circulation favouring polar air invasion to the South and East.

In spring (Figure 7b), the temperature seems to have the same pattern behaviour as in winter, but the amplitude of the variations is smaller. In the East, the SLP seems positively correlated with the temperature (ex. Kuujjuara-

a) winter

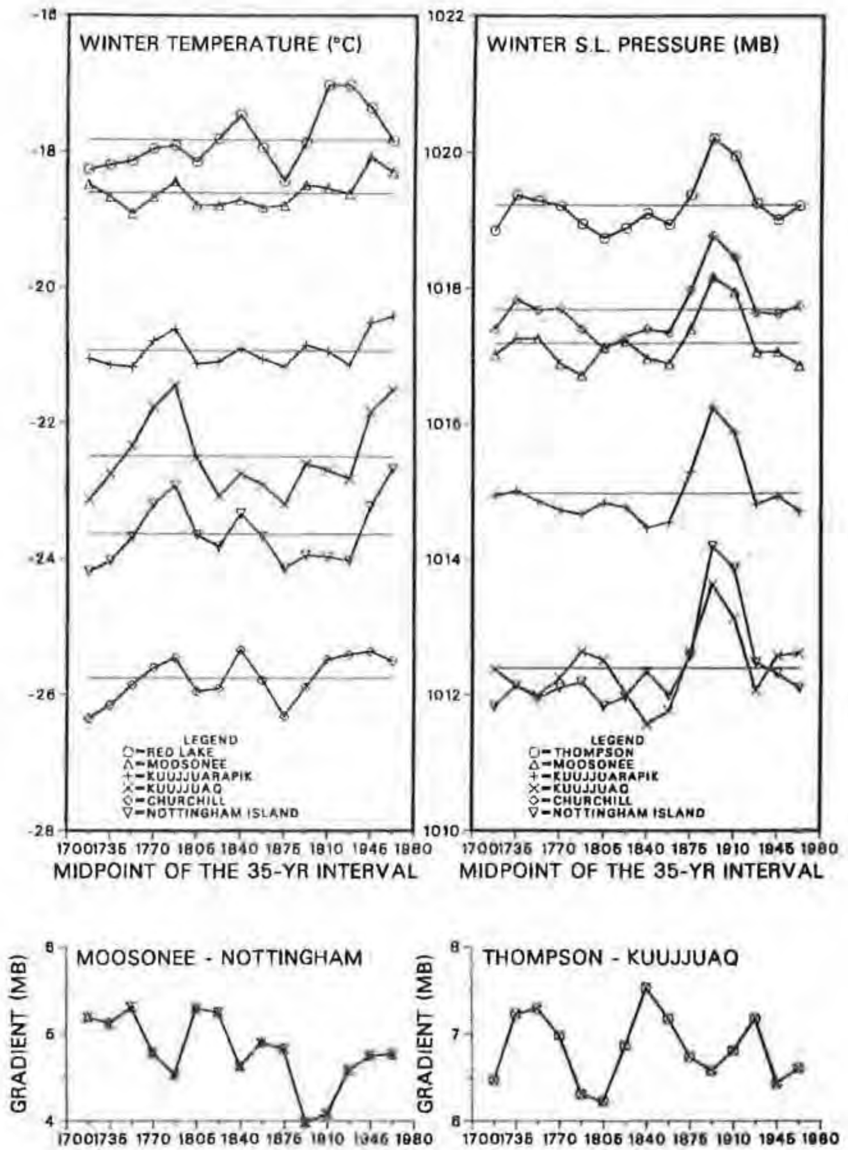
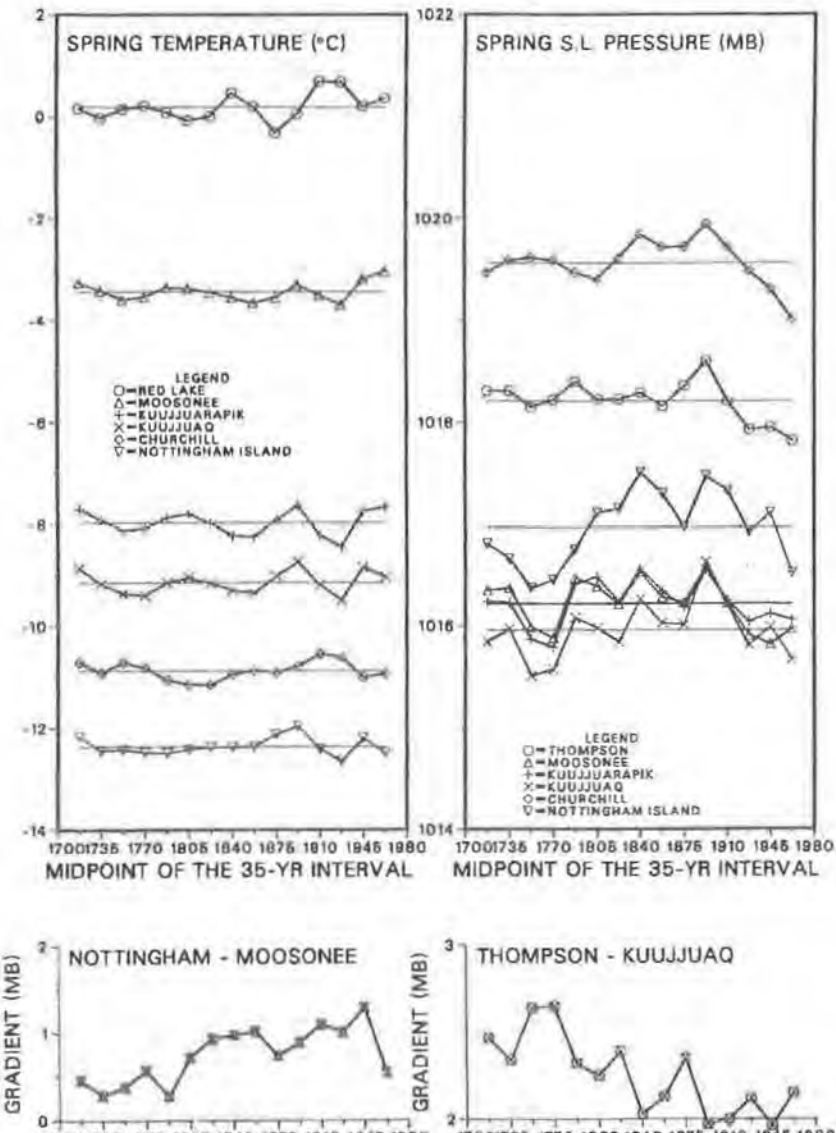


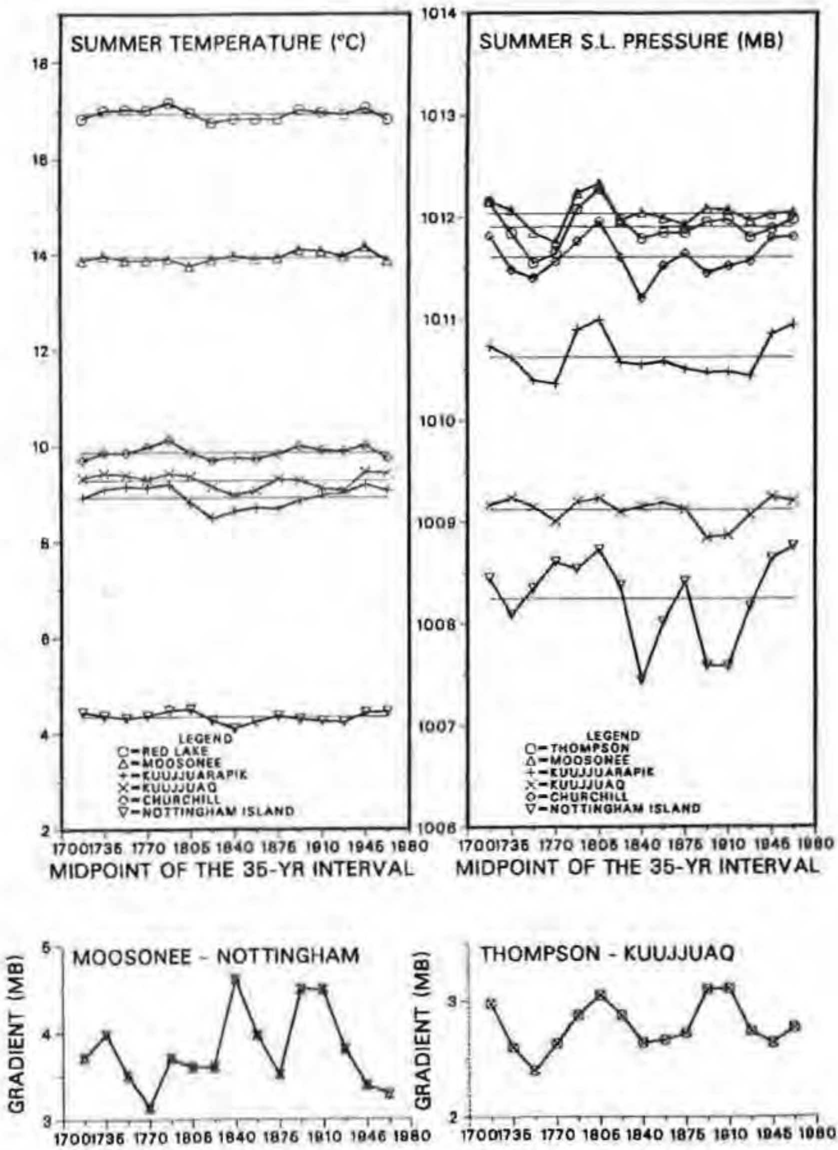

FIGURE 7. Trends of the reconstructed temperatures and SLP series: the means are computed over 35-year intervals by steps of 17.5 years. At the bottom, differences between SLP of extreme latitude (Moosonee and Nottingham Island) and extreme longitude (Thompson and Kuujjuaq) are drawn.

b) spring

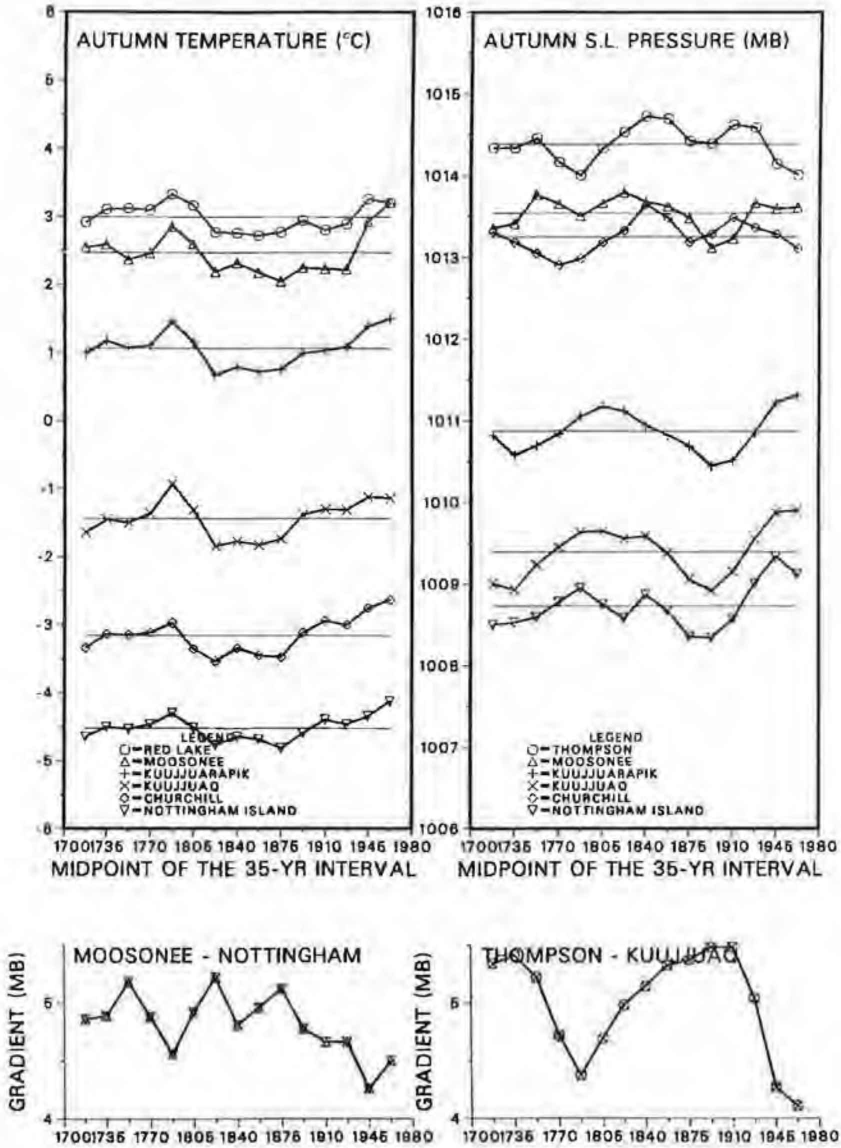


SPRING TEMPERATURE (°C)
LEGEND
□–RED LAKE
△–MOOSONEE
+–KUUJJUARAPIK
×–KUUJJUAQ
○–CHURCHILL
▽–NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
SPRING S.L. PRESSURE (MB)
LEGEND
□–THOMPSON
△–MOOSONEE
+–KUUJJUARAPIK
×–KUUJJUAQ
○–CHURCHILL
▽–NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
NOTTINGHAM - MOOSONEE
GRADIENT (MB)
THOMPSON - KUUJJUAQ
GRADIENT (MB)

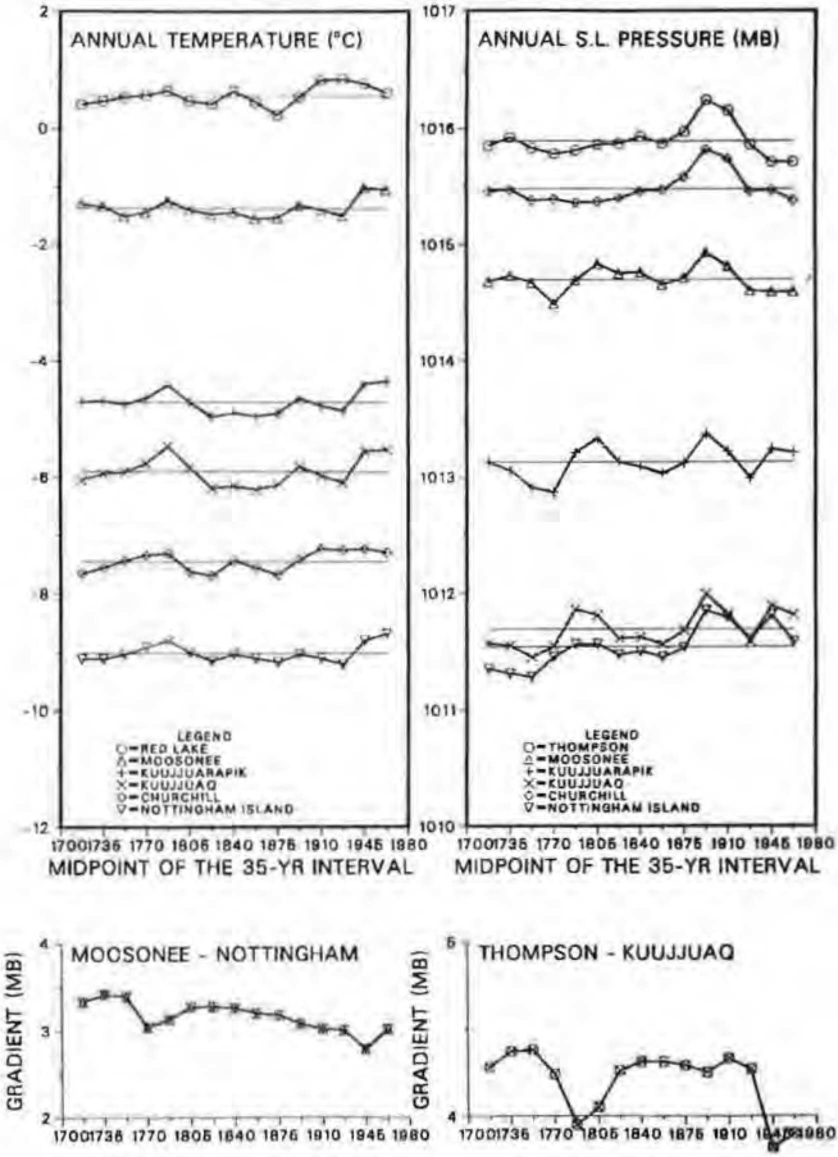
c) summer


SUMMER TEMPERATURE (°C)
LEGEND
○=RED LAKE
△=MOOSONEE
+=KUUJJUARAPIK
×=KUUJJUAQ
◇=CHURCHILL
▽=NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
SUMMER S.L. PRESSURE (MB)
LEGEND
○=THOMPSON
△=MOOSONEE
+=KUUJJUARAPIK
×=KUUJJUAQ
◇=CHURCHILL
▽=NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
MOOSONEE - NOTTINGHAM
GRADIENT (MB)
THOMPSON - KUUJJUAQ
GRADIENT (MB)

d) autumn


AUTUMN TEMPERATURE (°C)
LEGEND
O=RED LAKE
Δ=MOOSONEE
+=KUUJJUARAPIK
X=KUUJJUAQ
◇=CHURCHILL
∇=NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
AUTUMN S.L. PRESSURE (MB)
LEGEND
O=THOMPSON
Δ=MOOSONEE
+=KUUJJUARAPIK
X=KUUJJUAQ
◇=CHURCHILL
∇=NOTTINGHAM ISLAND
MIDPOINT OF THE 35-YR INTERVAL
MOOSONEE - NOTTINGHAM
GRADIENT (MB)
THOMPSON - KUUJJUAQ
GRADIENT (MB)

e) annual


ANNUAL TEMPERATURE (°C)
LEGEND
○=RED LAKE
△=MOOSONEE
+=KUUJJUARAPIK
×=KUUJJUAQ
◇=CHURCHILL
▽=NOTTINGHAM ISLAND
1700 1735 1770 1805 1840 1875 1910 1945 1980
MIDPOINT OF THE 35-YR INTERVAL
ANNUAL S.L. PRESSURE (MB)
LEGEND
□=THOMPSON
△=MOOSONEE
+=KUUJJUARAPIK
×=KUUJJUAQ
◇=CHURCHILL
▽=NOTTINGHAM ISLAND
1700 1735 1770 1805 1840 1875 1910 1945 1980
MIDPOINT OF THE 35-YR INTERVAL
MOOSONEE - NOTTINGHAM
GRADIENT (MB)
1700 1735 1770 1805 1840 1875 1910 1945 1980
THOMPSON - KUUJJUAQ
GRADIENT (MB)

pik: minimum of SLP and T around 1735-1769 and maximum around 1875-1909). In the West, the correlations seem to be negative, since the SLP's are relatively low in the 20th century. Table 8 confirms this. The zonal and meridional circulation indices are defined at the bottom of Figure 7b. It is clear that temperature increases of the 20th century were accompanied by an increase of zonality and a decrease of the meridional circulation. The Little Ice Age was characterized by a less intense zonal spring circulation and a less dominant Atlantic low pressure regime.

In summer (Figure 7c), the temporal variations are the weakest. The SLP pattern seem to be divided between two groupings according to the means and the variations: Nottingham and Kuujjuaq located often to the North or on the trajectory of the Arctic Front and the other stations more frequently situated to the south of this front. A positive correlation seems to exist between summer temperature and SLP for the southern stations, as warm air masses more frequently invade the northern regions. For the north-eastern stations, the linkage is more complex. The SLP difference between Thompson and Kuujjuaq, summarizing the meridional character of the circulation (and thus the warm air invasion to the North), is related negatively with the temperature in the South and the West.

In autumn (Figure 7d), the maxima take place in a more synchronous way at the end of the 18th and middle 20th centuries. PC analysis has shown the relatively homogeneous character of this season. The temperatures are positively correlated with the SLP gradient between East and West (Figure 7d, at the bottom). The Little Ice Age was marked by a strong meridional circulation in autumn.

The annual mean conditions are summarized in Figure 7e. Salient conclusions to be drawn are: (i) the Little Ice Age finished at the end of the 19th century; (ii) the annual temperature difference between the warm and cold periods (35 years) for the stations analyzed is between 0.5 and 0.9°C; (iii) low temperatures correspond generally to meridional circulation (the greatest amplitudes occur during the cold seasons, thereby influencing the annual means).

## 8. SYNOPTIC ANALYSIS

The 30 reconstructed temperature series are analysed by PC for the 1953-1979 interval. The first four PC's explains 86.6% of the variance. Table 9 presents the years which are linked to these PC's (positive and negative side). This indicates that eight, not necessarily independent, classes can be defined (see below).

The same analysis over 1700-1979 enables allocation of every year to one of these eight classes. The classes 1, 4, 5 and 7 are the most frequently represented during the coldest periods (before 1770 and 1805-1874) and the classes 2, 3, 6 and 8 are the most frequently represented during the 20th cen-

TABLE 9. Temperature variables influencing the most the first four PC and the years which are associated. C=cold and W=warm. The numbers of the corresponding classes are indicated in brackets.

| PC | variable | years − | years + |
|---|---|---|---|
| 1 | annual | (1) 1972, 1978 C | (2) 1953, 1968 W |
| 2 | Summer (opposition with Winter) | | (3) 1955, 1973 W |
| | Winter (opposition with Summer) | | (4) 1956, 1969 C |
| 3 | Spring | (5) 1954, 1967 C | (6) 1977 W |
| 4 | Autumn | (7) 1959 C | (8) 1971 W |

tury. This analysis describes, in a general sense, the climate of the Little Ice Age: generally cold with the possible exception in winter (mild winters are sometimes associated with cold summers). The year 1972 is the best approximation to represent this state.

Synoptic maps are presented (Figure 9) which show the geographical distribution of the climate patterns of these extreme years. Temperatures (°C) are expressed in terms of departures from the 1925-1983 mean (Figure 8) and SLP (mb) in absolute units (Figure 9). Class 1, represented by the two years 1972/1978, depicts the years with low annual temperature (−1 to −2°C). The maximum anomalies occurred in summer and autumn. Figure 8a shows maximum anomalies in the North. This class is in contrast with class 2 (1953/1968) having an anomaly of 1°C mainly around Hudson Bay and Quebec (Figure 8b). Clear differences are evident for the SLP fields between Figures 9a and 9b. A cold year corresponds to a strong pressure gradient (7 mb) with deeper cyclones located more to the North. A weak gradient (less than 3 mb) is characteristic of a warm year. Figure 8c shows that the warm autumn anomaly is important for northern Manitoba, Hudson Bay and Figure 9c shows that the high SLP extends to the West and the South, but the gradient is only 4 mb, while for a cold autumn, it can be 10 mb.

Class 3 (1955/1973) is characterized by a warm summer (1°C to 2°C) and a cold winter (0°C to −2°C). The summer anomaly is maximum in the North-West (Figure 8d) and the winter anomaly is important in the North (Figure 8e). Class 4 is the opposite to class 3 (1956/1969), with cold summers and warm winters. The winter positive anomaly is important in the East (Figure 8g) and the summer negative anomaly is important in the South-East (Figure 8f). Comparison of Figures 9d and 9f shows that high pressures climb to the North and Atlantic low pressures are deeper in a cold summer. Comparison of Figures 9e and 9g shows that warm winters are characterized by a generally higher SLP over the whole region and also be a stronger barometric gradient.

Class 5 (1954/1963/1967/1970) is characterized by a cold spring (Figure 8h) related to a northerly flux with strong highs in the West (Figure 9h). This is verified by comparison with the warm spring (Figures 8i and 9i) of class

6 (1977), when high pressure extends over the North-West and South, making a south-western flux.

The autumn of class 7 is cold (Figure 8j) mainly in the South-West. The north-eastern lows are deeper than usual (Figure 9j) and western highs are located in a more northern position. Class 8 (1971) has no particular anomaly.

In conclusion, the years 1972/1978, 1956/1969 and 1959 seem to be good models for the Little Ice Age. The temperature was cold during the whole year except during some winters which were sometimes milder in Quebec. A cold spring and autumn often prolonged the winter season mainly in the West. Zonal circulation was weak in winter and spring while the Arctic Front had a more southerly location. Other features were deeper Atlantic lows and weaker western highs.

## 9. CONCLUSIONS

Two kinds of data have been combined to produce climatic seasonal reconstructions for a large region centered on the Hudson Bay. Historical proxy series from the Hudson's Bay Company, compiled by several authors, are well related to climate, but they are characterized by many gaps. Tree-ring data are continuous; however, their linkage with climate is sometimes complex. It has been shown that the two kinds of data are complementary. Appropriate statistical methods permit reconstructions of seasonal temperature and sea-level pressure. First, standard transfer functions show that the available proxy series network is sufficiently representative of the temperature field for the region. Thus short-term variations have been reconstructed. Second, an alternative method, based on the closest analogues, enables correction of spurious long-term variations. It seems that the analogue method alone, may be able to yield good results as well, but the series should perhaps be first "prewhitened" to reconstruct high frequencies. This hypothesis needs to be checked.

From the reconstructions, it is clear that the 18th and 19th centuries were colder than the 20th on both an annual and seasonal basis. Differences of 0.5 to 0.9°C for annual temperatures between coldest and warmest 35-year intervals are obtained. These cold periods are characterized by a less intense zonal circulation in winter and spring, and low pressures linked to a more southern trajectory of the Arctic Front in summer and autumn. Eight classes of synoptic situations have been defined, which characterize the temperatures of the 1700-1979 period. Thus the years 1972/1978, 1956/1969 and 1959 are representative of the cold periods, mainly 1805-1839, and the years 1953/1968, 1955/1973 and 1977 are representative of the warm years.

## ACKNOWLEDGEMENTS

This work has been performed thanks to a post-doctoral fellowship of the Natural Science and Engineering Research Council of Canada, thanks to the

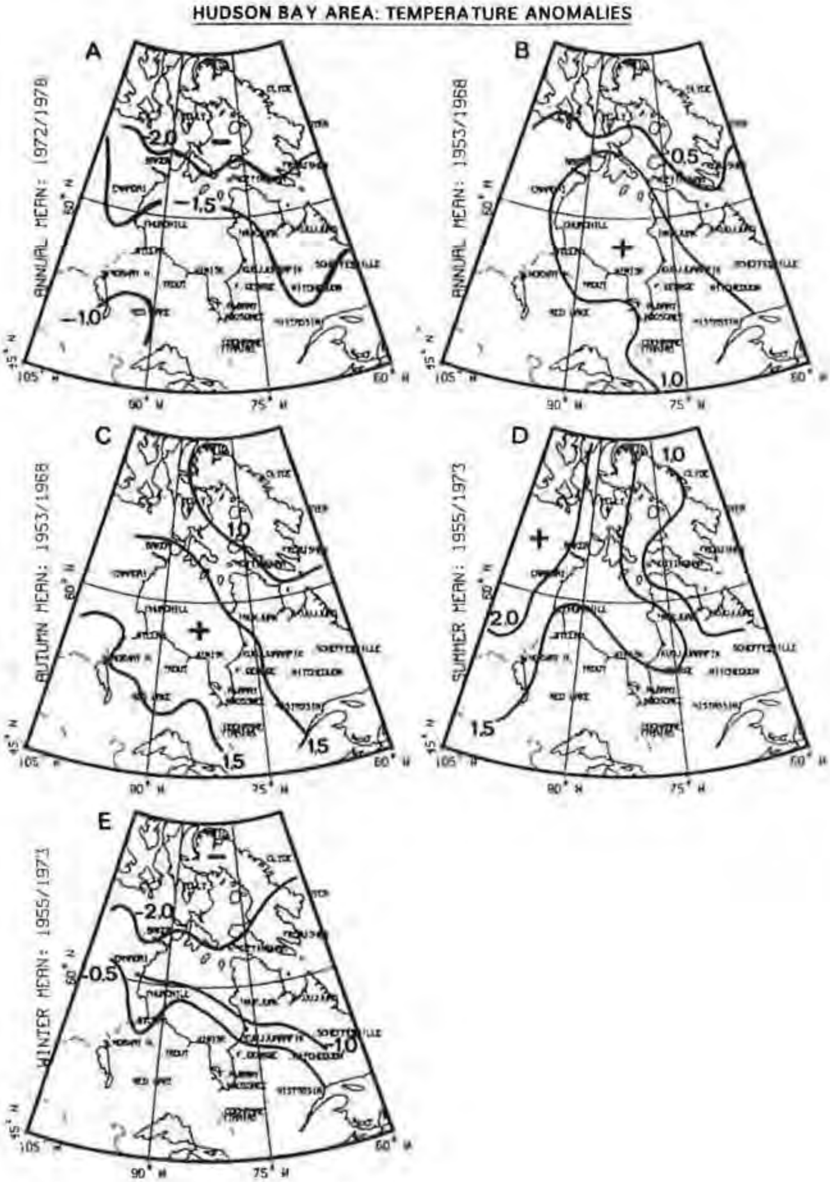
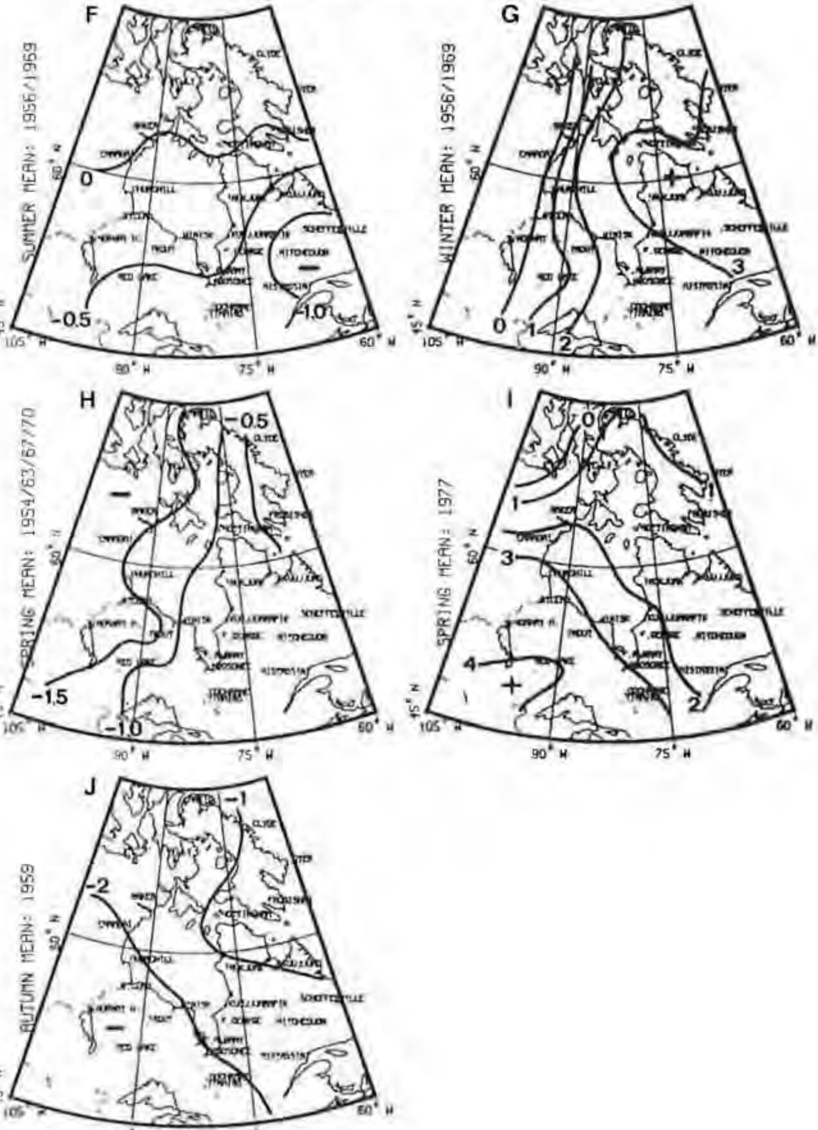



FIGURE 8. Synoptic maps of actual seasonal temperature anomalies (°C) for the years representing the eight selected classes (see text).

HUDSON BAY AREA: TEMPERATURE ANOMALIES



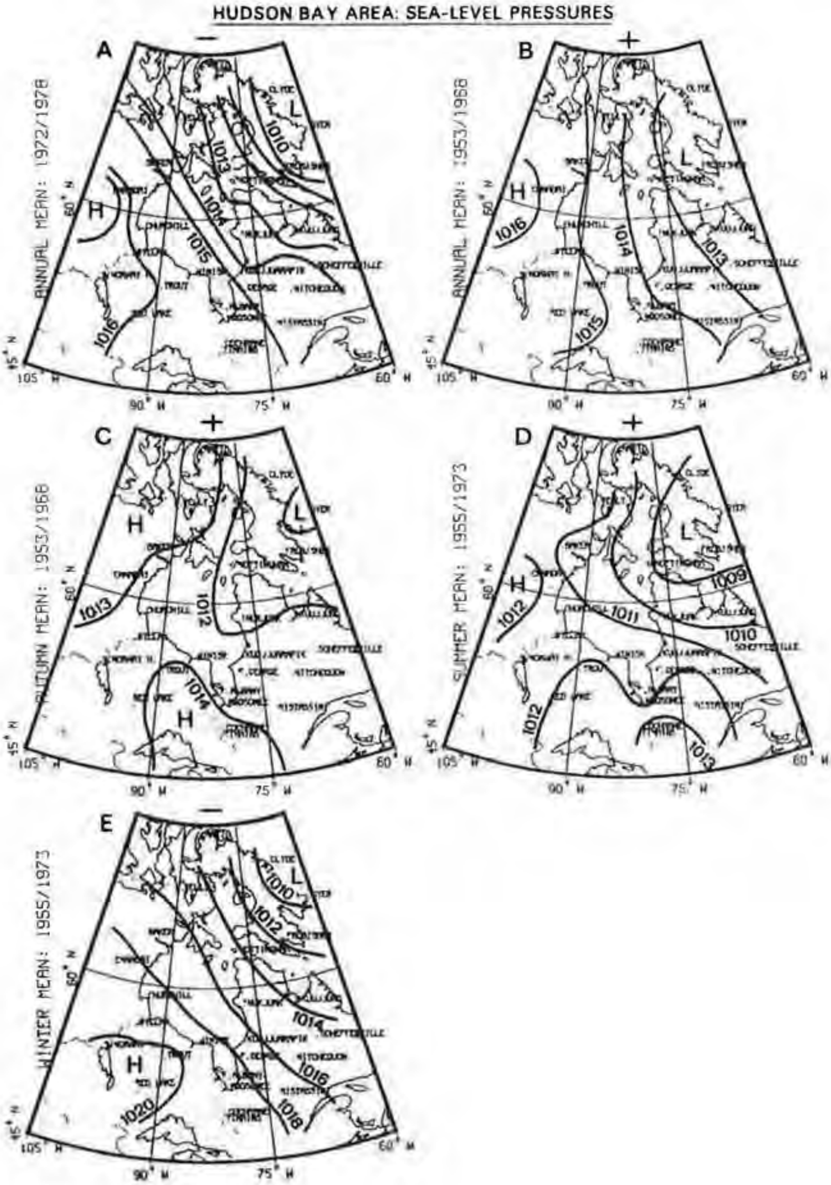
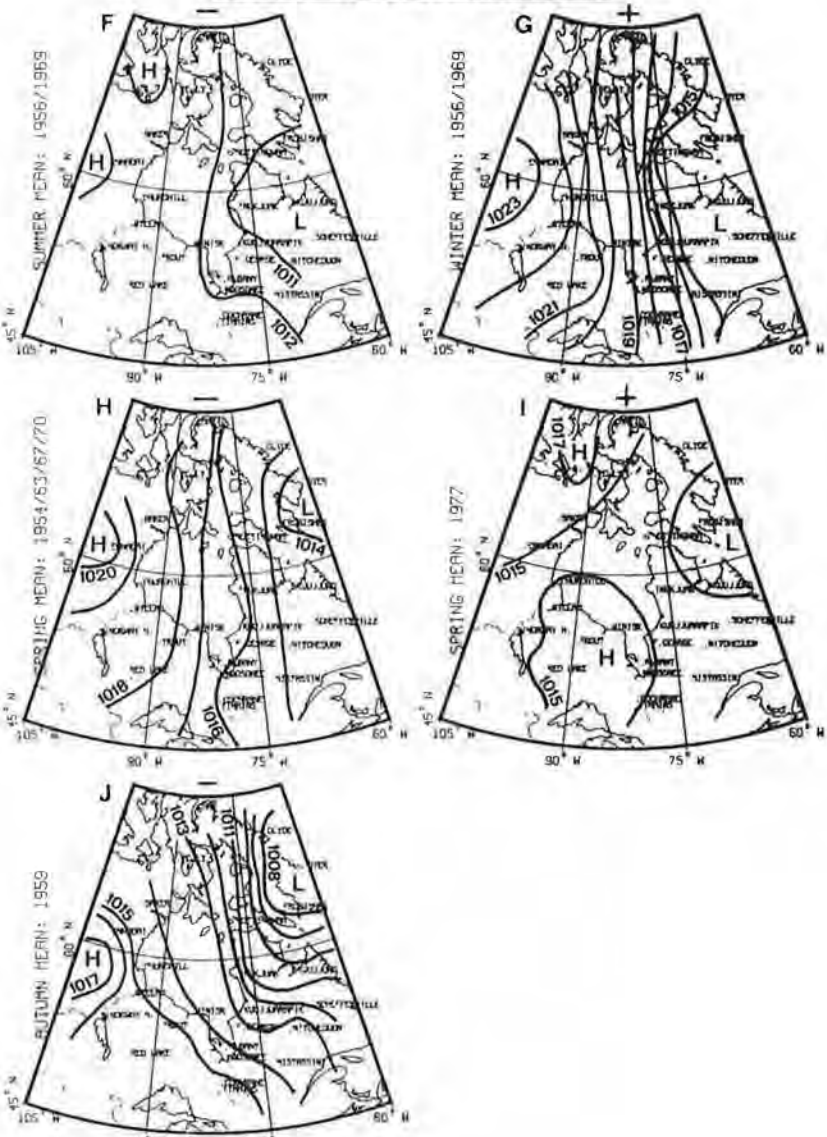



FIGURE 9. Synoptic maps of actual sea-level pressures (mb) for the years representing the eight selected classes (see text).

**HUDSON BAY AREA: SEA-LEVEL PRESSURES**



material support of the Atmospheric Environment Service, and thanks to the advice, comments and encouragement of Mr. B.F. Findlay. Thanks also to Mr. L. Steinberg, M. Thomas, and J. Padro for helpful comments.

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# News and Comments
# Nouvelles et commentaires

## RETIREMENT OF K.D. HAGE, UNIVERSITY OF ALBERTA

*Edward Lozowski*
Department of Geography, University of Alberta, Edmonton, Alberta

On June 30, 1985, Keith Donald Hage, Professor of Meteorology for eighteen years in the University of Alberta, retired.

Although he intends to remain active in research and continues to maintain an office at the University, he will be sorely missed for the inspiration of his teaching and the wisdom of his collegial advice. His retirement was marked by two events at the University attended by friends and relatives as well as present and former colleagues and students. Gifts of both a humourous and serious nature were offered and accepted graciously. These included several antique and modern weather instruments and various paraphernalia to enhance the enjoyment of his equestrian and gardening hobbies. The "pièce de résistance" was a framed illuminated manuscript featuring the Tower of the Winds in Athens, beautifully crafted by Mr. Geoff Lester. All of his colleagues and students wish Keith good health and stimulating activity in his retirement.

## 1985 FRIENDS OF CLIMATOLOGY MEETING

*J.H. McCaughey*
Department of Geography, Queen's University, Kingston, Ontario

The Friends of Climatology met at Queen's University on June 26 and 27. The meeting was hosted by the Department of Geography and 25 participants attended.

The Friends of Climatology started in 1970 with the inaugural meeting at the University of Windsor. Annual meetings have been held every year since that time with the exception of 1979 and 1981 (Table 1). The purpose of this group is to foster interactions between persons interested in climatological work. Each year one person is designated as "Climatologist-in-Orbit" whose purpose is to visit various institutions and give a presentation on some current research topic. This past year, Stewart Cohen (AES) was the orbiter, and we are all in his debt for an excellent effort in reporting on his work in applied climatology. His presentations dealt with the assessment of the impact of climatic change in the Great Lakes Basin and on formulating a methodology for the assessment of climatic impact.

At the June meeting of the Friends, Stewart reported on his impressions. He emphasized the need to better coordinate the visit of the orbiter to neighbouring institutions in order to minimize both travel time and travel costs.

Other speakers in the morning session of the meeting included Ben De Cooke of the Detroit office of the American Corps of Engineers. He spoke about the role of climate forecasts in the prediction of lake levels in the Great Lakes system. Neil Trivett (AES) described the work he is currently doing in the Arctic on the monitoring of background air pollution. In particular, the establishment of the baseline station at Alert and some initial results were discussed.

In the afternoon session, Bob Stewart (AGR. CANADA) gave a presentation on the impact of climate cooling on spring wheat yields in Western Canada. The potential impact of nuclear winter was touched upon and provoked some interesting discussion. Andy Bootsma (AGR. CANADA) followed with an interesting report on the role of climate in agricultural management decisions at the farm level with particular emphasis on the Maritime region. Finally, John Lewis (McGill) discussed his current work on sea ice in the Arctic. From remote surface temperature scans, it was evident that ice thickness and the presence of open water areas play a key role in surface heat flux.

Our thanks go to all the speakers. Each one showed that climatology is alive and active! Next year the meeting will be held in AES, and Neil Trivett has kindly agreed to act as chairperson for 1986.

Looking forward to seeing everyone there.

TABLE 1: Friends of Climatology – Meeting Places 1970 – 1985, Ontario/ Quebec

| |
|---|
| 1970 – University of Windsor |
| 1971 – McMaster University, Hamilton |
| 1972 – Atmospheric Environment Service and York University, Downsview |
| 1973 – McGill University and Sir George Williams University (Concordia), Montreal |
| 1974 – Agrometeorology Department, Agriculture Canada, Ottawa |
| 1975 – Scarborough College, University of Toronto, Scarborough |
| 1976 – University of Guelph, Guelph |
| 1977 – Atmospheric Environment Service Headquarters, Downsview |
| 1978 – Wilfrid Laurier University, Waterloo |
| 1979 – No meeting |
| 1980 – University of Windsor, Windsor |
| 1981 – No meeting |
| 1982 – McMaster University, Hamilton |
| 1983 – University of Ottawa, Ottawa |
| 1984 – Erindale College, University of Toronto, Mississauga |
| 1985 – Queen's University, Kingston |

## FRIENDS OF CLIMATOLOGY – THE BEGINNING*

*Morley Thomas*, Toronto, Ontario

Credit for the concept of Friends of Climatology and for contacting his "fellow climatologists along the Great Lakes-St. Lawrence axis" must be given to Ken Hare. Sometime after Ken's arrival at the University of Toronto, he wrote to several of us in the fall of 1969 to say that Marie Sanderson, at the University of Windsor, was willing to host a meeting in February 1970. The idea took root immediately and a dozen or so of us travelled to Windsor for the first meeting of the Friends on Friday evening and Saturday morning February 27 and 28, 1970.

The name Friends of Climatology was borrowed, I believe, from the Friends of the Pleistocene, a geology and geography group in the United States. From the start we were determined that this should be a non-organization, i.e. no officers, no dues, no formal papers, no annual report – in short, no-all-those-things we were already doing full time in our careers in university and government. And it worked! We sat around a big table at Windsor and discussed things of importance to our discipline and our profession and after a luncheon, which Marie convinced the President of the University to provide for us, we agreed we should meet again next year.

John Davies of McMaster volunteered to host the 1971 meeting at his university, and thus it fell to McMaster to organize the facilities for the next meeting and to advise everyone soon enough so they could plan to attend. For several years the torch was passed each year, the torch consisting of not much more than an address list. The address list grew too, perhaps surprisingly since climatology was still coming out of its "dark ages" then and did not have the appeal to atmospheric scientists and geographers that it does today.

Although we did have a "non-organization", we did recognize the common problems and opportunities which needed discussion. In his letter regarding the possibility of the first meeting, Ken Hare expressed them well –

a) The chance to improve and differentiate the curriculum in climatology at all levels;
b) Possible common facilities of research and publications including a journal or bulletin;
c) Exchange of lectures, students, and facilities between centres;
d) Relations with the developing cult of environmental studies, pollution control and similar cross-disciplinary fields;
e) Climatology at the International Geographical Union 1972 Congress.

Now, 15 or so years later, you must agree that solid progress has been made in at least some of these areas.

In the spring of 1972 the Third Annual Meeting was held at York University and AES Downsview. We in AES were proud to show off our new building and there were at least 40-50 in attendance at the York sessions, which included a dinner, and the Saturday meetings at AES including lunch. Gordon McKay and I felt better after those Toronto meetings too, since many AES meteorologists and geographers attended. For the first two meetings, we had played down the attendance of other AES people for fear of overloading the Friends with a government hue.

The next year, 1973, the meetings were organized by Ben Garnier and others at McGill and we enjoyed a brief taste of Montreal night life. In March 1974 Wolfgang Baier and company at Agriculture Canada organized the meetings, and in 1975 the meetings took place at Scarborough College. April 4 and 5 turned out to be beautiful late winter days in Toronto but the previous night, April 3/4, several hundred staff had been storm bound at AES Downsview.

So the Friends of Climatology have withstood storms and the lack of an organization (so much so that meetings were not held a couple of times!), periods of budget restraint, and the retirement or pseudo-retirement of several of us. It has however gained many new, young, vigorous Friends, and 15 years or so from now, I am sure they will recall the meetings of the 1980's as fondly as several of us do the meetings of the early 1970's.

*Ed. Note – An early attempt at "networking".

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## NOVA SCOTIA CLIMATE ADVISORY COMMITTEE

The Nova Scotia Climate Advisory Committee held its inaugural meeting December, 1982 with twenty-three in attendance. There have been four meetings since then, about every six months. There has been much discussion about the role of this group and continued moderate interest, indicated by the attendance of about fourteen people at each meeting.

The primary benefit so far has been the exchange of information on climate-related activities ongoing throughout the province. An inventory of non-AES climate data and climate publications has been compiled and circulated to committee members. The committee has encouraged AES to move forward on archiving non-standard data. An Atlantic Region Climate Workshop, to be held October 30th in Dartmouth, is being organized to provide a forum for climate-related activites in the region. Published proceedings will provide a compendium of people active in climatology in the region.

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## ATLANTIC REGION CLIMATE WORKSHOP

A one day workshop will be held at the Bedford Institute of Oceanography, October 30, 1985.

The theme of the workshop will be Climatic Data Networks. Invited papers will examine questions such as:

- Who operates them and why?
- What are the results and benefits?
- What equipment is used or available?
- What is needed for the future?

The program will be rounded out by a panel and discussion period.

The workshop is sponsored by the Nova Scotia Climate Advisory Committee and the Canadian Climate Program. For further information please contact either:

Mr. Peter Dzikowski
Program Chairman, Climate Workshop,
Nova Scotia Dept. of Agriculture & Marketing,
P.O. Box 550, Truro, Nova Scotia  B2N 5E3
*or*
Mr. William Richards, Secretary,
N.S. Climate Advisory Committee
Atmospheric Environment Service
1496 Bedford Highway, Bedford, Nova Scotia  B4A 1E5

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## NEW BRUNSWICK METEOROLOGICAL COMMITTEE

*James F.L. Knight*, P. Eng, Chairman NBMC
Environment New Brunswick, Fredericton, NB

The N.B. Meteorological Committee was formed in 1976, to better coordinate the collection and dissemination of climatological data in the province. It is made up of representatives of several federal and provincial governments and agencies and the University of New Brunswick, and a secretariat, Don Murray of the Flood Forecast Centre, supplied by Environment New Brunswick.

The mandate of the committee has expanded by concensus of the members to include a broader scope of meteorological interest. It now serves as a liaison to the Atmospheric Environment Service for most weather-related needs of the provincial member institutions.

A major accomplishment of the committee is the preparation of the "Climatological System Review" for the province. This resulted in the amalgamation of some stations, upgrading of others, and the addition of new ones where most needed. By coordinating the resources of the agencies involved, New Brunswick is now on its way toward achieving adequate spatial coverage.

A computer archive has been set up at the University of New Brunswick for all climatological data for the province since such records became available. These data are readily available to all of the agencies.

The committee has assisted AES with establishment of a Weatheradio system, and with the design and implementation of new forecast products in the region. Surveys have been carried out to determine the response to, or special problems with, and of these products.

The chairman attended the recent meeting of the Canadian Climate Advisory Committee, the first meeting which included the provincial representatives. The NBMC will now serve as the provincial advisory committee to this larger body. We look forward to further sharing of information at the national level.