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An Analysis of the Homogeneity of Long-Term Temperature Records From Some Principal Canadian Climatological Stations

by
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ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

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ABSTRACT

This report examines the homogeneity of long-term temperature records (greater than 70 years) from some principal Canadian climatological stations. Seven Canadian principal climatological base stations are selected in order to represent a cross-section of climatic types. Each selected station is currently located at a city airport but the earlier portions of their long-term records were derived from observations at their respective urban locations. Two methods of testing temperature homogeneity are applied and compared. The first test consists of a seasonal analysis of mean daily temperature range for the period of record at each station. The second test, applied to seasonal maximum and minimum temperatures, compares a base station index with another index generated by a combination of several auxiliary stations in the surrounding region. The first test provides a convenient method for identifying the suitability of an homogeneous record or revealing a record with an inhomogeneity of greater than 1 °C. The second test identifies the nature, magnitude and significance of a discontinuous inhomogeneity of less than 1°C.

RÉSUMÉ

Ce rapport examine l'homogénéité des relevés de températures à long terme (sur plus de 70 années) de certaines stations climatologiques principales du Canada. On a sélectionné sept stations climatologiques principales du Canada, stations de base pour obtenir un échantillon représentatif des types climatiques. A l'heure actuelle, chaque station sélectionnée se situe à un aéroport urbain, mais on a établi les premières parties des relevés à long terme à partir d'observations effectuées aux emplacements urbains respectifs. On applique et compare deux méthodes de test de l'homogénéité des températures. Le premier test constitue une analyse saisonnière de la gamme des températures quotidiennes moyennes pour la période des relevés à chacune des stations. Le second test, portant sur les températures maximales et minimales saisonnières, compare l'indice de station de base avec un autre indice découlant d'une combinaison de plusieurs stations auxiliaires de la région environnante. Le premier essai fournit une méthode commode pour déterminer la pertinence d'un relevé homogène ou il identifie un relevé dont la non-homogénéité dépasse 1 C. Le second test établit la nature, l'ampleur et l'importance d'une non-homogénéité discontinue de moins de 1 C.

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1. INTRODUCTION

Climatic change studies require the best available data. These types of studies are often concerned with accuracies of a few tenths of a degree over time spans of 30 to 100 years. Changing climates are most often interpreted through temperature readings taken at a height of 1.5 m above the surface of the earth. There are two main problems associated with many long-term records obtained in this manner. The precision required from the data by climatic change studies is often much greater than the precision with which the measurements were originally taken. In addition, the older portions of most long-term temperature records are based on observations taken within expanding urban areas and then abruptly moved to rural airport locations. This latter problem is responsible for discontinuities, or inhomogeneities, in many long-term temperature records from these stations.

Temperature changes which are observed over long periods of time likely have both an apparent and a real component. Figure (1) shows the possible components of a long-period temperature change. The real component is subdivided into climatic and local components. The climatic component is the subject of climatic change studies. The local component is influenced by alterations in the environment near the observation site such as the influence of urban expansion. The apparent component of a temperature change is affected by a number of factors. The most important of these factors is a change in instrument location such as a move from an urban to a rural airport location.

Canada has developed a network of two distinct classes of climatic observation stations. The main network consists of principal climatological stations usually located at airports and staffed 24 hours per day by well-trained observers who observe and record numerous climatic elements. This network of stations was developed in the 1930's and 1940's with the advent of an air service in this country. A secondary network of stations consists of voluteer observers who cooperate with the federal service by recording only one or two observations per day of a few climatic elements, usually temperature and precipitation. Many long-term Canadian temperature records of at least 70 years in length are comprised of records from both classes of observation stations. The earlier portions of these records belong to the second observational class with measured temperatures having been subjected to the anthropogenic influences of urban expansion. The latter portions of these records belong to the first observational class with better quality control of the observed elements. The change from an urban to an airport location also represents a possible discontinuity in the long-term temperature record due to the changing microclimate in the vicinity of the new of the instrument shelter.

Most of the better known studies dealing with global or hemispheric temperature changes have used data from stations subjected to both urban influences and airport relocations (Griffiths and Vining, 1984). Figure (2) shows the approximate mean annual temperature trend in the Northern Hemisphere as suggested by many authors. A distinct warming trend existed until about 1940. This was followed by a cooling trend into the 1960's with a recent reversal to slightly warmer temperatures again. Figure (3) shows the possible theoretical changes in mean annual temperature due to relocation and modification of the local environment. There is a distinct possibility that some of the temperature variation evident in Figure (2) is related to the early urban expansion, airport relocation and to the steady growth of the airport environment. Most of the long-term Canadian temperature records have similar histories to that which is depicted in Figure (3). Their combined records must therefore be approached with caution.

With the exception of an analysis of Toronto temperature and precipitation data (Gargett, 1965) no statistical homogeneity analysis has been applied to long-term temperature data from Canadian stations. However, shortly after the relocation of many stations to airports, a number of city and airport records were subjectively combined "in order to provide more meaningful long-term averages for the public" (Thomas, 1975). Some records from larger urban centres such as Vancouver, Toronto and Montreal were not combined because of obvious differences. However, the records from several other smaller urban locations such as Calgary, Regina and more recently Saskatoon were combined and have remained so in the Atmospheric Environment Service digital archive.

The purpose of this report is twofold. Firstly, a preliminary test will be applied to some long-term Canadian temperature records representing both combined and non-combined records but all of which have been subjected to a history similar to that which was described in Figure (3). The test consists of an analysis of the seasonal mean daily temperature range for the period of record at each station. This will be done in order to determine whether or not an inhomogeneity might exist in the record. Secondly, a seasonal homogeneity analysis will be applied to the same long-term temperature records using

FIGURE (1) Possible components of a long-period temperature change. Griffiths and Vining, (1984), p. 104.

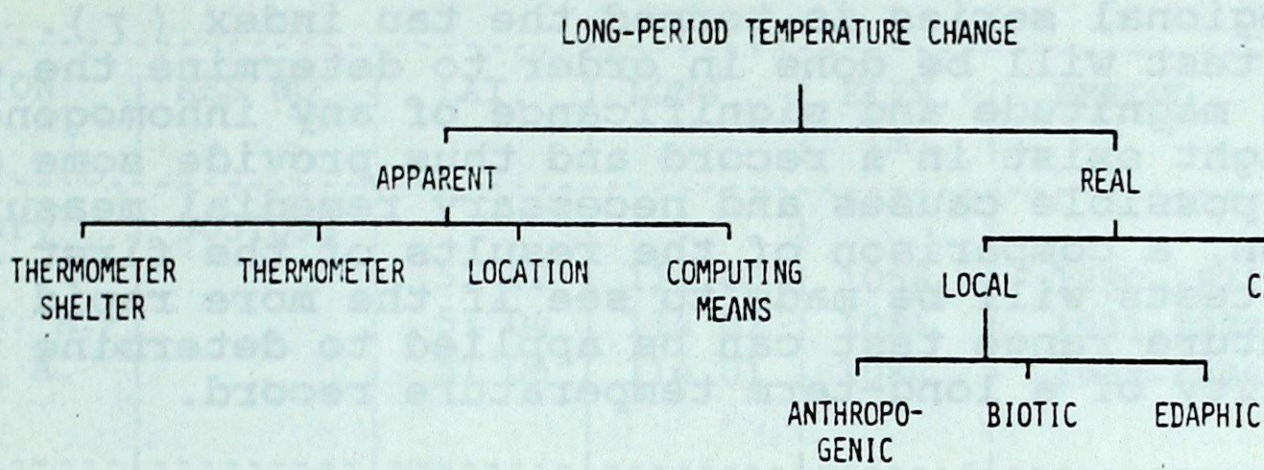


FIGURE (2) Northern Hemisphere approximate mean annual temperature trend as suggested by many authors. Griffiths and Vining (1984), p. 106.

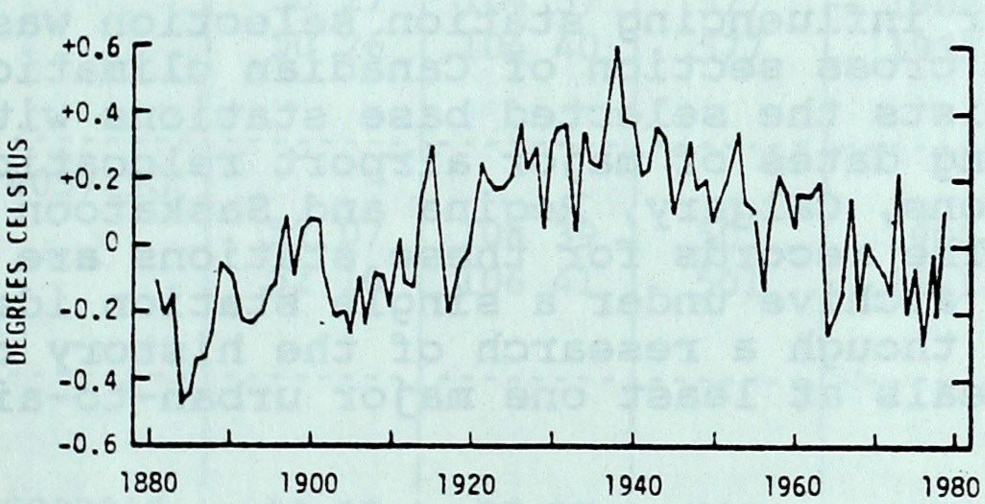
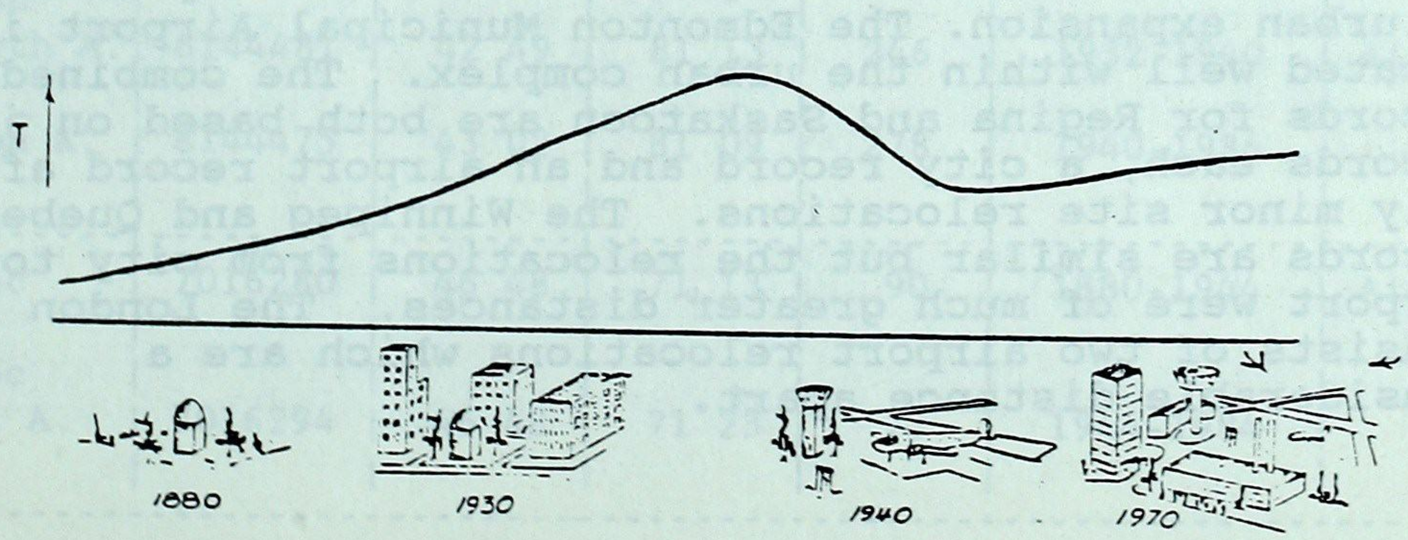


FIGURE (3) The possible theoretical changes in mean annual temperatures due to relocation and modification of the local environment. Griffiths and Vining (1984), p.106.



the operating procedure for a homogeneity analysis of a single temperature record as outlined by Mitchell (1961). This test consists of a comparison of the series under examination, or base station index, with another series generated by a suitable combination of several surrounding, or auxiliary, stations in the region of the base station. This regional series is termed the tau index (τ). The second test will be done in order to determine the exact nature, magnitude and significance of any inhomogeneity that might exist in a record and thus provide some clues as to the possible causes and necessary remedial measures. In addition, a comparison of the results of the first and second tests will be made to see if the more rapid temperature range test can be applied to determine the suitablity of a long-term temperature record.

2. BASE STATIONS

Seven Canadian principal climatological base stations were selected for this study. Each selected station is currently located at a city airport but the earlier portions of their long-term records were derived from observations in their respective urban locations. A major factor influencing station selection was a desire to represent a cross section of Canadian climatic types. Table (1) lists the selected base stations with their corresponding dates of major airport relocations. Three of these stations, Calgary, Regina and Saskatoon are combined stations. The records for these stations are stored in the AES digital archive under a single station identification number even though a research of the history of each station reveals at least one major urban-to-airport site relocation.

The history of each station is, aside from a major airport relocation, rather unique. The combined Calgary record has experienced nine site relocations since its inception in the 1880's. The major airport relocation, however, was in 1931 with a secondary airport relocation in 1938. The airport relocation for the Edmonton record was only of minor distance to the Municipal Airport but the entire record has been subjected to the steady influences of urban expansion. The Edmonton Municipal Airport is now located well within the urban complex. The combined records for Regina and Saskatoon are both based on just two records each, a city record and an airport record after only minor site relocations. The Winnipeg and Quebec City records are similar but the relocations from city to airport were of much greater distances. The London record consists of two airport relocations which are a considerable distance apart.

TABLE (1)

Canadian base stations used for the seasonal analysis of mean daily temperature range and for the homogeneity analysis of maximum and minimum temperatures

STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
*Calgary	3031093					
City		51 02	114 05	1058	1890-1931	Airport(1931)
Munic. A.		51 04	114 02	1084	1931-1938	Airport(1938)
Int'l A.		51 06	114 01	1084	1938-1984	
Edmonton	3012195	53 33	113 30	658	1890-1937	Airport(1937)
Edmonton Munic. A.	3012208	53 34	113 31	671	1937-1984	
*Regina	4016560					
City		50 27	104 37	577	1902-1931	Airport(1932)
Regina A.		50 26	104 40	577	1932-1984	
*Saskatoon	4057120					
City		52 07	106 39	503	1902-1941	Airport(1941)
Sask. A.		52 10	106 41	501	1941-1984	
Winnipeg St John's College	5023243	49 53	97 07	232	1875-1938	Airport(1938)
Winnipeg Int'l A.	5023222	49 54	97 14	239	1938-1984	
London S.	6144505	42 59	81 12	246	1885-1932	Airport(1932)
London Lambeth A.	6144481	42 49	81 13	246	1932-1940	Airport(1940)
London A.	6144475	43 02	81 09	278	1940-1984	
Quebec	7016280	46 48	71 13	90	1880-1944	Airport(1944)
Quebec Int'l A.	7016294	46 48	71 23	73	1944-1984	

* Stations combined into a single record in the AES digital archive.

3. SEASONAL ANALYSIS OF MEAN DAILY TEMPERATURE RANGE

Temperature range (Tmax - Tmin) can be quite sensitive to changes in instrument exposure (Kemp and Armstrong, 1972). This variable can often display either a sudden or gradual change in magnitude which can be associated with changing environmental conditions in the vicinity of the thermometer screen. Seasonal plots of mean daily temperature range which do not remain fairly constant through time have likely been subjected to both the real and apparent components of a temperature change as described in Figure (1). Changes through time to a lower range of temperatures indicate the observation of either lower maximums or higher minimums, or both. Changes to a higher range of temperatures would indicate the opposite. In addition, a significant change in the variance of temperature range could possibly indicate a change in the observational program such as a change in the times of day at which observations are taken or the precision with which observations were taken.

A plausible explanation for such changes would be related to alterations in the microclimatic conditions in the vicinity of the thermometer screen whether it be through actual relocation of the screen or through modification of the local environment. Another explanation might involve the real component of climatic change. However, an abrupt change in temperature extremes due to climatic change would be quite unlikely to occur at precisely the same moment in time as an instrument relocation.

The Fortran program (RANGE) was developed to calculate monthly and seasonal mean daily temperature range for each selected Canadian base station. The seasons used in the analysis were the standard climatological seasons; winter being the mean of December of the prior year, January and February, spring the mean of March, April and May, summer the mean of June, July and August and fall the mean of September, October and November. Figure (4) to Figure (10) in Appendix I show seasonal plots of mean daily temperature range for the seven base stations. Table (2) to Table (8) in Appendix I show the Student t-test and F test calculations comparing the seasonal means and variances, respectively, of the 30 year periods prior to and after an airport relocation at the corresponding base station.

The seasonal plots for Calgary in Figure (4) all display obvious differences between the period prior to and the period after the first airport relocation in 1931. Table (2) shows that the means and variances of these two periods are all significantly different for all seasons with the exception of the spring variance. In all other cases the mean range and the variance is significantly higher for the earlier city record.

The Edmonton seasonal plots in Figure (5) are similar in direction to the corresponding Calgary plots but, unlike Calgary, do not show the abrupt discontinuity at the time of the airport relocation in 1938. Instead, there is a gradual reduction in the temperature range through the years. This could possibly indicate the influences of urban expansion on the observed temperatures. Table (3) shows the means of the two periods to be significantly different in all seasons. However, the variances in all seasons are not significantly different.

The Regina seasonal plots in Figure (6) and the accompanying statistics in Table (4) show significant differences in specific seasons only. The winter and spring means and winter variances before and after the 1932 airport relocation are significantly different. The plots for Saskatoon in Figure (7) also show differences in specific seasons only. Table (5) shows the fall means and winter variances to be significantly different before and after the airport relocation in 1941. In all significant cases for both Regina and Saskatoon both the means and the variances prior to the airport relocations were greater than those after the relocations.

The Winnipeg seasonal plots in Figure (8) and their respective statistics in Table (6) show few significant differences between the city and airport periods. Only the summer means are significantly different with the city record prior to 1938 having a higher range than the airport record after 1938.

The seasonal plots for London in Figure (9) and their respective statistics in Table (7) show significant differences in mean temperature range in all seasons. The variances in all seasons were not significantly different. Only the London South and London Airport records were compared. It was felt that the 1933-40 period of the London Lambeth record was too short for effective comparison with the other two records. As seen in the previous stations the mean temperature range for the earlier city record was significantly higher than that for the airport record.

The Quebec City seasonal plots in Figure (10) and their respective statistics in Table (8) also show significant differences in mean temperature range in all seasons. In the case of Quebec City, however, the situation is reversed to that which has been observed at the previous stations. The temperature range prior to the airport relocation in 1944 was significantly lower than that after the relocation.

By plotting seasonal values of mean daily temperature range and statistically comparing the periods prior to and after a major instrument site relocation it appears possible to determine the existence of an inhomogeneity in a long-term temperature record. Evidence of inhomogeneities exist to varying degrees in all of the base stations tested. It does not, however, identify the nature of an inhomogeneity. A much more definitive test is required in order to determine whether maximum or minimum temperatures, or both, are responsible, the extent of the magnitude and the significance of the inhomogeneity.

4. SEASONAL HOMOGENEITY ANALYSIS OF MAXIMUM AND MINIMUM TEMPERATURES

The operational procedure for the homogeneity analysis applied to each Canadian base station was developed and outlined by Mitchell (1961). It consists of a comparison of the series under test, a base station index, with a suitable combination of data from several auxiliary stations in the region surrounding it. The combined series, or tau index (τ), yields a relatively noiseless estimation of the true temperature variation in the region of the auxiliary stations. This method of homogeneity analysis is quite old but has been recommended by the World Meteorological Organization (Mitchell et. al.,1966) and more recently (Griffiths and Vining, 1984) as the best available methodology for testing the homogeneity of a single temperature series.

Relative homogeneity tests between two stations have been found to be quite inadequate. The series being tested in these types of analyses are often indistinguishable from the other series at typical inhomogeneity magnitudes of 0.5° to $2.5^{\circ}C$. This is due to low signal-to-noise ratios. In addition, when the test series does show a significant departure it is equally difficult to determine which of the two records contains the absolute inhomogeneity.

By combining the records from several auxiliary stations in the region evidence of relative inhomogeneities can be translated directly into conclusions about absolute inhomogeneities in the base station series. A number of factors ultimately determine the best procedure for combining several auxiliary series' into a single regional series. These factors include the length of the base record being investigated and the length of the available auxiliary station records, the relative incidence of missing observations, the density of stations in the region, the relative incidence of auxiliary station relocations and the climatic uniformity of the region.

Mitchell (1961) describes two methods of testing for absolute inhomogeneities in a test series. The area mean index is simply the averaging of mean temperatures for all of the stations in the region. Each term in the test series is expressed as a departure from the mean value of the regional series. The main problems associated with this particular analysis are the usual high number of missing observations in an auxiliary series and also the varying impact of station relocations on the combined regional series. A second method involves the development of a tau index by converting the mean temperature series at each auxiliary station into a series of first temperature differences. Dates of known station relocations are edited and then the corresponding first-differences for each auxiliary station in the region are averaged to yield a regional tau index. Network changes and missing data have a much smaller impact on the tau index than on the area mean index. The tau index leads to much lower expected errors on both a monthly and a seasonal basis.

Mitchell (1961) also outlines the advantages of a seasonal homogeneity analysis over a monthly analysis. The effect of a change in exposure on seasonal mean temperatures is a good estimate of its effect on the monthly mean temperatures in that season. Also, the error variance of seasonal mean temperatures is only about 1/3 that of monthly means. This is because errors in measurement in monthly means tend to be serially independent. Finally, estimates of the magnitude of an inhomogeneity based on seasonal means can be made with more confidence than those based on monthly means.

4.1 Operating Procedure

The following is a step-by-step account of the operating procedure, as outlined by Mitchell (1961), to test for the homogeneity of a single temperature series with the use of a tau index. The Fortran program (MAXCALG) was developed to implement this procedure.

(1) Selection of the base stations. Potential base stations consist of long-term Canadian climatological stations which have had uninterrupted temperature records since at least 1915. A search of the station

history reveals a major change in observation site location from city to airport usually in the 1930's or 1940's. Seven test stations have been selected for this study but many more remain to be analyzed.

(2) Selection of the auxiliary stations to be combined into a tau index. Each station must lie within a 2° latitude/longitude square from the base station. The station has at least 40 consecutive years of record. The station history reveals that it has not suffered more than an average of one major site relocation per decade. Stations must be well distributed spatially with respect to the base station. Stations must exhibit the same basic temperature regime as the base station.

(3) The monthly time series at each auxiliary station is transformed into a series of backward first-temperature differences beginning in 1984. For example 1984 equals 1983 minus 1984, 1983 equals 1982 minus 1983, etc.

(4) Each first-difference series is edited by deleting each value which brackets a known change in station location.

(5) An areally representative first-difference series is obtained by averaging the edited first-difference series' for all auxiliary stations.

(6) Individual station first-differences are compared with the corresponding value in the areally averaged series and any value which deviates by more than 2° C and is not adjoined by differences in both the preceding and following years is deleted. This process is called the 2° discrepancy and prevents large errors from entering the comparisons.

(7) The areal average is re-calculated and cumulatively summed backward from the most recent date to obtain a reconstructed series. This process begins with an arbitrary constant of 20° C in order to prevent negative values.

(8) The tau index is calculated as departures from the most recent 10 year average of the reconstructed series.

(9) The base index is calculated as departures from the most recent 10 year average of the base station series.

(10) The tau index series is subtracted term by term from the base index series. The new series, the base-tau difference series, is a direct measure of any inhomogeneities that might be present in the base station series. The expected values in this series should all be equal to zero if the base station series is completely homogeneous.

(11) A seasonal base-tau difference series is calculated using the standard climatological seasons.

(12) The 95% confidence bands for the seasonal tau index are calculated on the assumption that tha tau index is Gaussian distributed. They are assigned half-widths equal to twice the standard error of the seasonal tau index. The calculation of the error variance and the standard error of the tau index is given in Appendix III.

(13) The seasonal base-tau differences and the 95% confidence bands, or standard errors of the tau index, are plotted. If the base-tau series lies consistently within the confidence bands the base series is assumed to be homogeneous in that season. If, however, the base-tau difference series deviates considerably beyond the confidence bands for an extended number of years a tentative inhomogeneity is assumed but not verified until application of an objective test of significance.

(14) A test of statistical significance is applied to all seasonal mean data concerning the times of airport relocations. The magnitude of the suspected inhomogeneity is calculated by comparing 10 year averages of the seasonal base-tau differences on either side of the date of the airport relocation. The test statistic is calculated from the formula;

$$\frac{|M|}{\sqrt{v(M)o}} = \text{Test Statistic} \quad \begin{cases} > k : \text{inhomogeneous} \\ < k : \text{homogeneous} \end{cases}$$

where, M = the magnitude of the estimated inhomogeneity, v(M)o = variance of M under the null hypothesis of a homogeneous record. When k = 2; the 95% confidence level which is appropriate for a discontinuous inhomogeneity.

A detailed calculation of v(M)o is given in Appendix IV.

4.2 Seasonal Homogeneity Analysis

Figure (11) to Figure (24) in Appendix II show the seasonal time series' of base-tau differences for both maximum and minimum temperatures for each base station. Also included are the 95% confidence bands or twice the standard of the seasonal tau index. These charts indicate the profiles of inhomogeneities present in each base station series within the limits of random sampling error in the base and tau series'. In the case of a homogeneous base station series and a reasonably stable tau index the base-tau difference series will always be close to zero with a variance which is small in 1984 but increases backward in time at a rate equal to the increase in the error variance of the tau index.

All base stations were analyzed for homogeneity for the period 1915-84. This was done because of the general lack of auxiliary station data prior to this 70 year period. Each set of maximum and minimum charts in Appendix II pertaining to a specific base station is accompanied by two tables. The first table for each base station gives a list of the auxiliary stations used to obtain a tau index. The final column in these tables show the number of auxiliary station relocations in the 70 year period. The second table for each station gives the seasonal magnitudes (M) of the suspected inhomogeneities for the 10 year period after minus the 10 year period prior to an airport relocation. A test statistic greater than 2 represents an inhomogeneity at the 95% level while a value greater than 3 is a significant inhomogeneity at the 99% level.

An examination of the Calgary charts in Figure (11) and Figure (12) reveals a maximum temperature inhomogeneity in all seasons prior to the airport relocation in 1931. Minimum temperatures are quite homogeneous. Table (10) shows the magnitudes of the maximum temperature inhomogeneities. They range from $-1.3^{\circ}C$ in winter to $-2.3^{\circ}C$ in summer. This means that the maximum temperatures measured at the airport location, in winter for example, were $1.3^{\circ}C$ less than those measured at the city location prior to the 1931 station relocation. These observations compare favorably with those found in the temperature range test where there was an abrupt fall in range at the time of relocation.

The Edmonton charts in Figure (13) and Figure (14) also compare favorably with the temperature range tests. There is distinct evidence of continuous inhomogeneities in both maximum and minimum temperatures in all seasons in the Edmonton record. The positve slopes of the base-tau differences indicate the gradual rising of both maximum and minimum temperatures. This can be related to the effects of urban expansion. The seasonal magnitudes and test statistics in Table (12) obviously do not handle this very well because of the gradual nature of the inhomogeneity.

The Regina Charts in Figure (15) and Figure (16) do not reveal an inhomogeneity in winter as suggested by the temperature range test. In addition, they do reveal both maximum and minimum summer inhomogeneities while the range test did not. Inhomogeneities are also indicated in spring maximums and minimums and fall minimums. In all significant cases, maximum temperatures were measured higher and minimum temperatures were measured lower at the city location with respect to the airport location. The Saskatoon charts in Figure (17) and Figure (18) reveal slight inhomogeneities in spring maximum and summer minimum temperatures. This does not correspond with the results of the range test which suggested winter and fall inhomogeneities. For both Regina and Saskatoon the indicated inhomogeneities are less than 1° C in magnitude.

The Winnipeg charts in Figure (19) and Figure (20) and the accompanying magnitudes and test statistics in Table (18) do not reveal any significant inhomogeneities in any season for either temperture extreme. This corresponds with the previous range test which only hinted at a slight inhomogeneity during summer.

The London charts in Figure (21) and Figure (22) and the accompanying Table (21) reveal maximum temperature inhomogeneities in spring, summer and fall and a near inhomogeneity in winter as well. This corresponds with the results of the range test and shows maximum temperatures to have been measured higher at the London South location than at the airport location.

The Quebec City charts in Figure (23) and Figure (24) and the accompanying Table (22) also support the results of the range test. Highly significant inhomogeneities are evident in minimum temperatures during all seasons. Minimum temperatures were measured 1.0° C to 1.5° C higher at the city location than at the airport location. The minimum temperature plots all show a distinct break in 1944 but the inhomogeneity continues at a smaller magnitude into the early 1960's. Inhomogeneities are also evident in winter and summer maximum temperatures but of a smaller magnitude than the minimum temperature inhomogeneities. These inhomogeneities are of about the same magnitude, about 0.8° C , but city maximums were measured higher in the winter and lower in the summer. The continuous inhomogeneities found in minimum temperatures are not evident in the maximum temperatures.

5. SUMMARY AND RECOMMENDATIONS

The organization and research of auxiliary station data and histories, respectively, is the most time consuming aspect of the homogeneity analysis. It would therefore seem appropriate to consider the use of the temperature range test as a rapid means of identifying the suitability of a long-term temperature record. The range test appears to be a reliable method of rapidly identifying the presence of larger inhomogeneities of greater than 1°C. This was seen in the Calgary, London and Quebec City records. When inhomogeneities are smaller, in the order of 0.5 ° C to 1.0 ° C, however, the range test does not seem to be quite so sensitive. This was evident in the Regina and Saskatoon records. It did prove to be quite effective in determining the homogeneity of the long-term Winnipeg record. The range test also clearly indicated the continuous inhomogeneity in the Edmonton record though the long-term trend it identified could have, in part, been caused by the real component of climatic change without prior knowledge of the history of the station.

In most cases a base station series can be corrected to homogeneity with little difficulty. For a seasonal series with a discontinuous inhomogeneity, the necessary corrections can be taken directly from the calculated seasonal magnitude values found in the tables accompanying the base-tau difference plots. In the case of a continuous inhomogeneity, as in the Edmonton record, the rate of change of temperature must be calculated and substituted for the appropriate magnitude value. Further analysis is required, however, for a monthly series. Estimates of monthly magnitudes are plotted with their 95% confidence limits. A curve is next fitted to these monthly magnitudes. The smoothness of the curve depends on the extent of the confidence limits. The monthly values of this curve are then used as estimates of the magnitude of the inhomogeneity in each month.

It is necessary to separate the real and apparent components of change in long-term temperature records prior to application to climatic change studies. Two tests have been outlined to examine the homogeneity of some long-term Canadian temperature records. The first test consisted of an analysis of seasonal mean daily temperature range (Tmax -Tmin) for the entire period of record at each station. Abrupt changes in temperature range were found to have occurred at precisely the same year as a major observation site relocation at some stations. At another station, where the influence of urban expansion was strong, a more gradual change in temperature range was observed. Very little difference in temperature range was observed at other stations.

The second test consisted of a seasonal homogeneity analysis designed to compare a base station temperature series with a regional series derived from several surrounding auxiliary stations. Maximum and minimum temperature series' were examined for the same long-term Canadian temperature records that were used in the temperature range tests. This test appears to be an effective means of identifying the nature, magnitude and significance of a discontinuous inhomogeneity. It is also effective in identifying the nature and overall magnitude of a continuous inhomogeneity. The correction of a record to homogeneity consists of a relatively straightforward prodedure based on the calculated magnitudes of the observed inhomogeneities. The temperature range test would appear to be a convenient means of both identifying the suitability of a homogeneous record and revealing a record with an inhomogeneity of greater than 1 $^{\circ}$ C. However, when an inhomogeneity is small, between 0.5 $^{\circ}$ C and 1.0 $^{\circ}$ C, the temperature range test appears to be inadequate.

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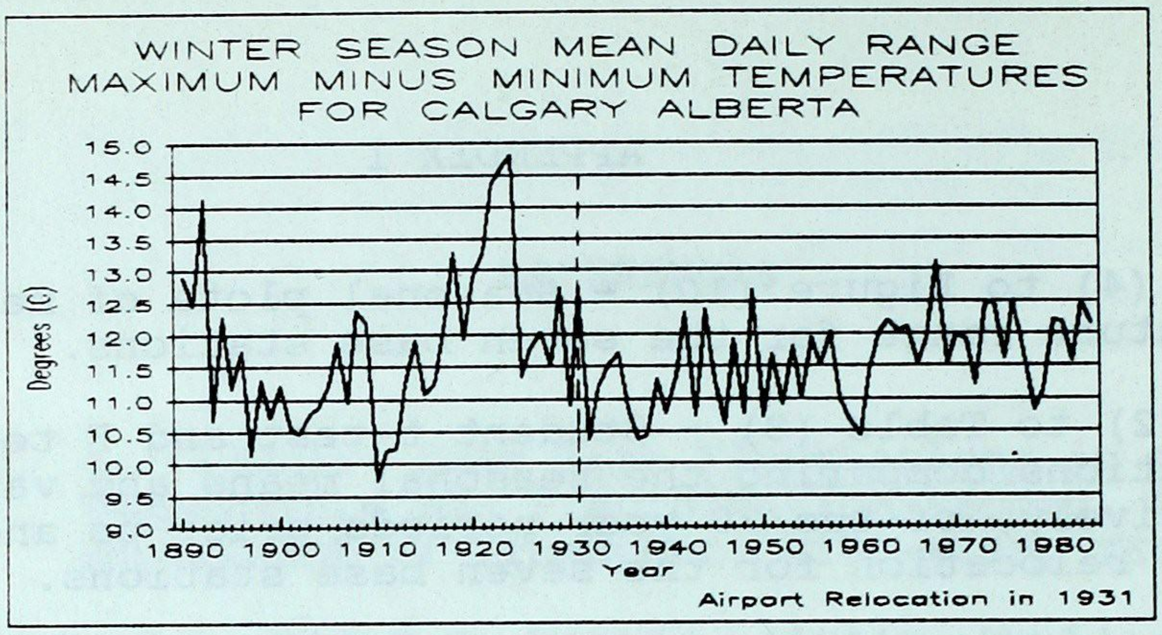
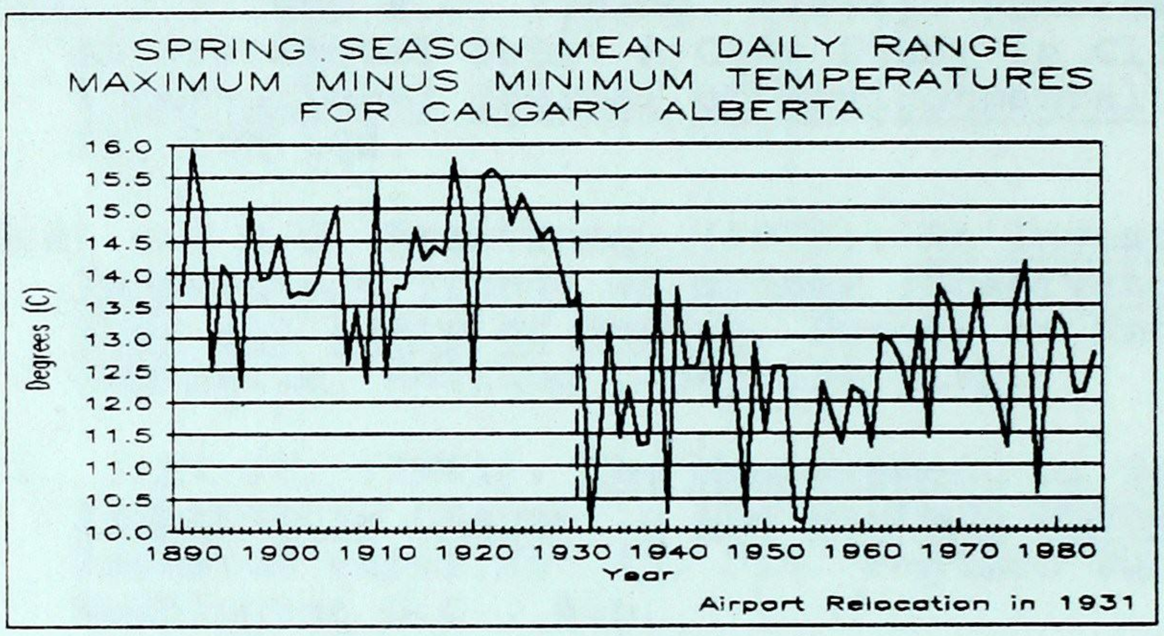
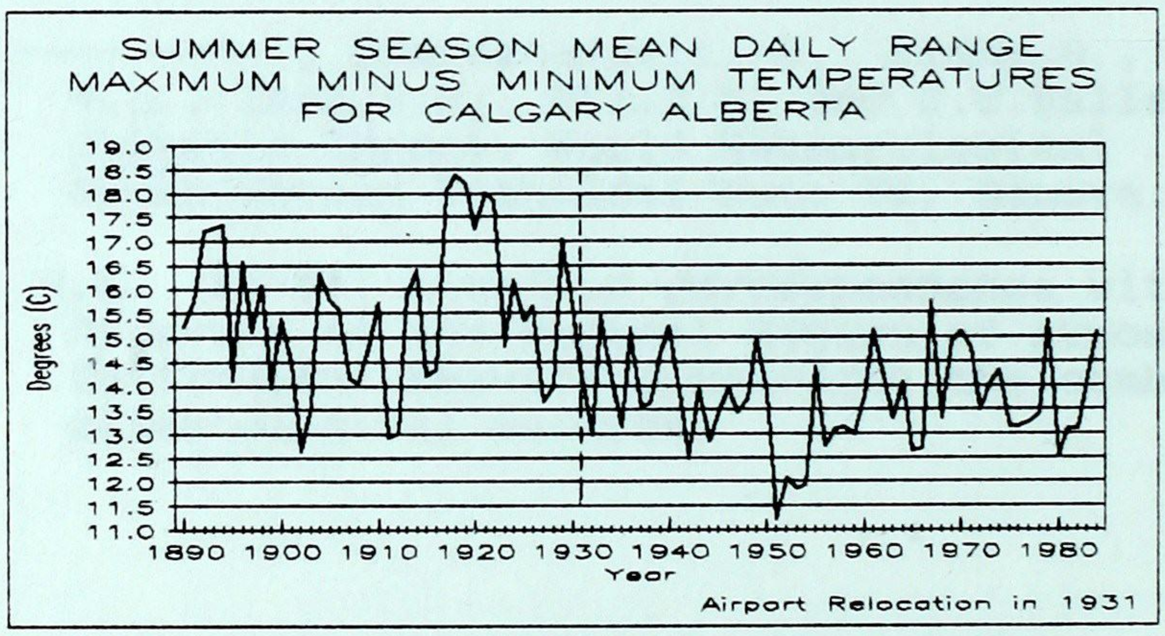
APPENDIX I

Figure (4) to Figure (10) - Seasonal plots of mean daily temperature range for the seven base stations.

Table (2) to Table (8) - Student t-test and F test calculations comparing the seasonal means and variances, respectively, of the 30 year periods prior to and after an airport relocation for the seven base stations.


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Degrees (C)
Year
Airport Relocation in 1931


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Degrees (C)
Year
Airport Relocation in 1931


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Degrees (C)
Year
Airport Relocation in 1931

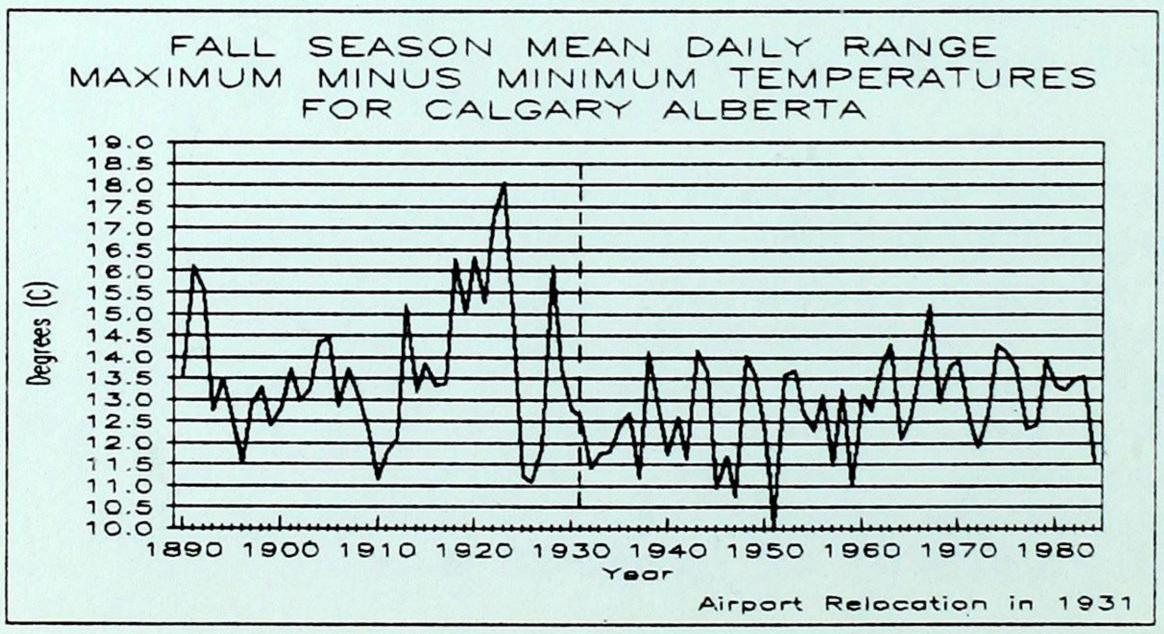
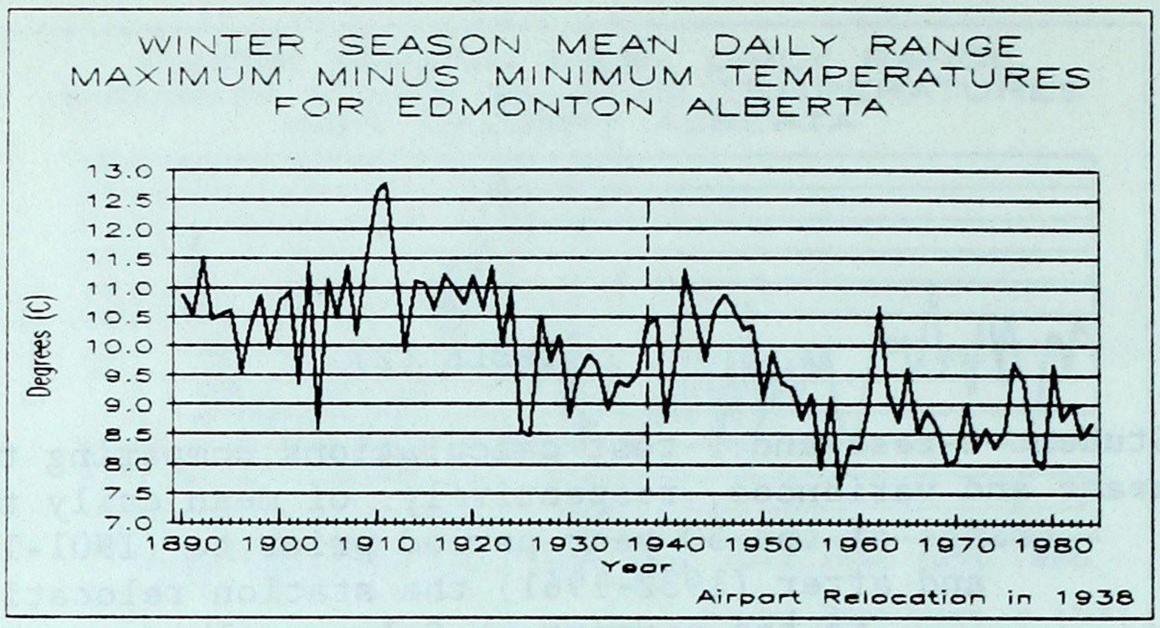
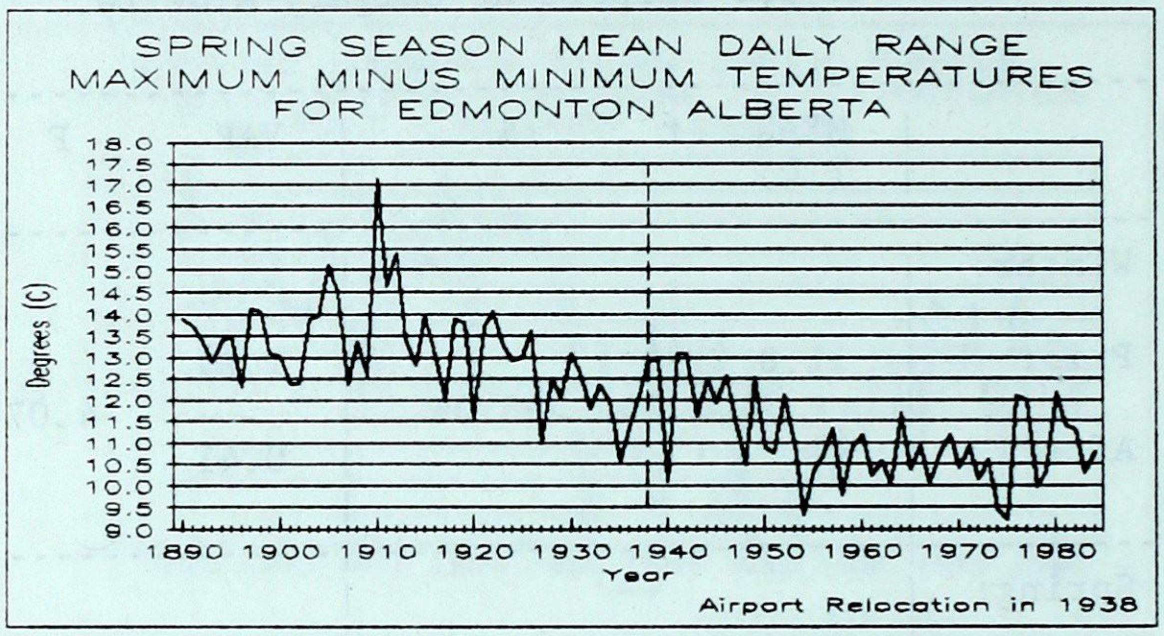

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Degrees (C)
Year
Airport Relocation in 1931

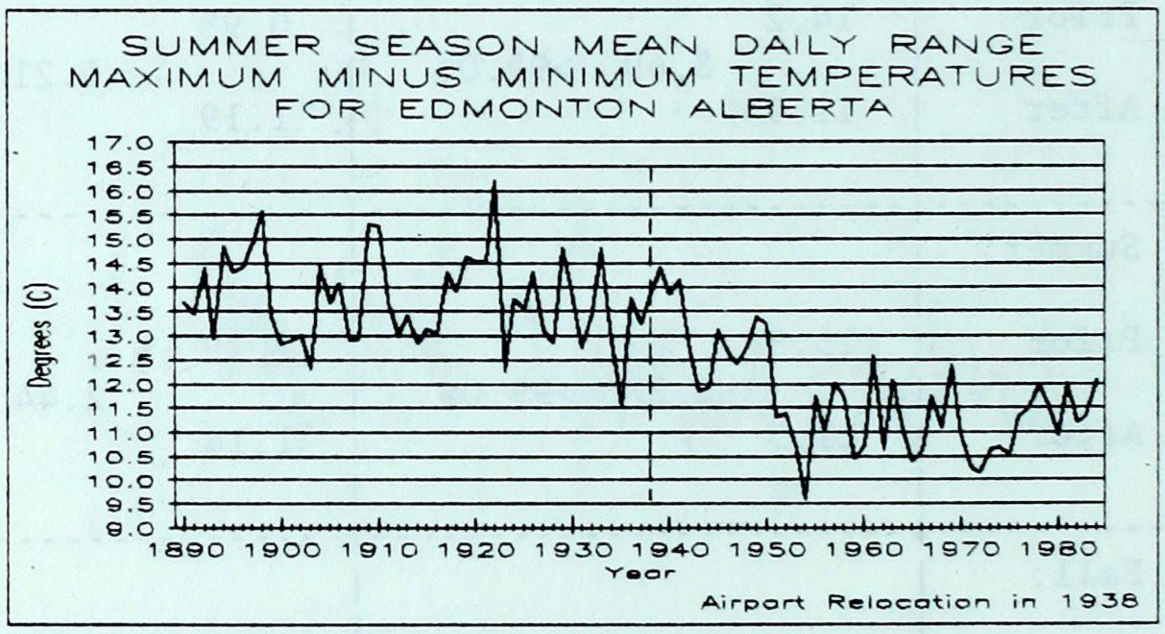
TABLE (2)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1901-1930) and after (1932-1961) the station relocation to the airport at Calgary Alberta.

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	11.8	2.14	>95.0%	1.67	4.07	>99.0%
After	11.2			0.41		
Spring:						
Prior	14.2	8.69	>99.0%	0.98	1.21	<90.0%
After	11.9			1.19		
Summer:						
Prior	15.5	5.27	>99.0%	2.79	2.44	>99.0%
After	13.5			1.14		
Fall:						
Prior	13.8	3.71	>99.0%	3.23	2.69	>99.0%
After	12.4			1.20		


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Degrees (C)
Year
Airport Relocation in 1938


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Degrees (C)
Year
Airport Relocation in 1938


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Degrees (C)
Year
Airport Relocation in 1938

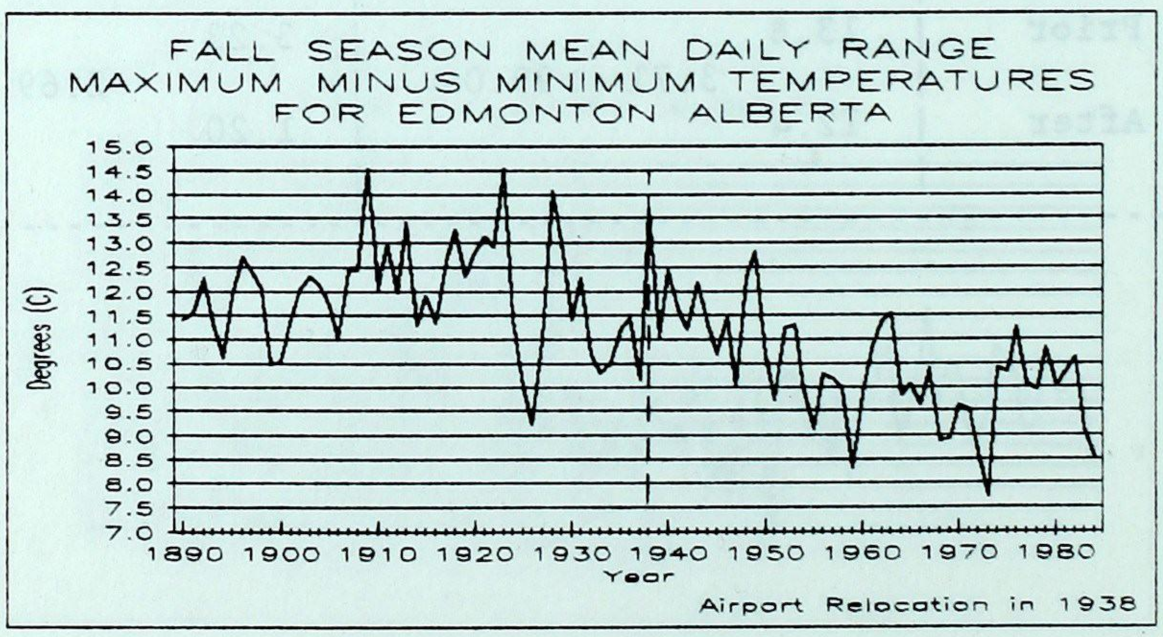
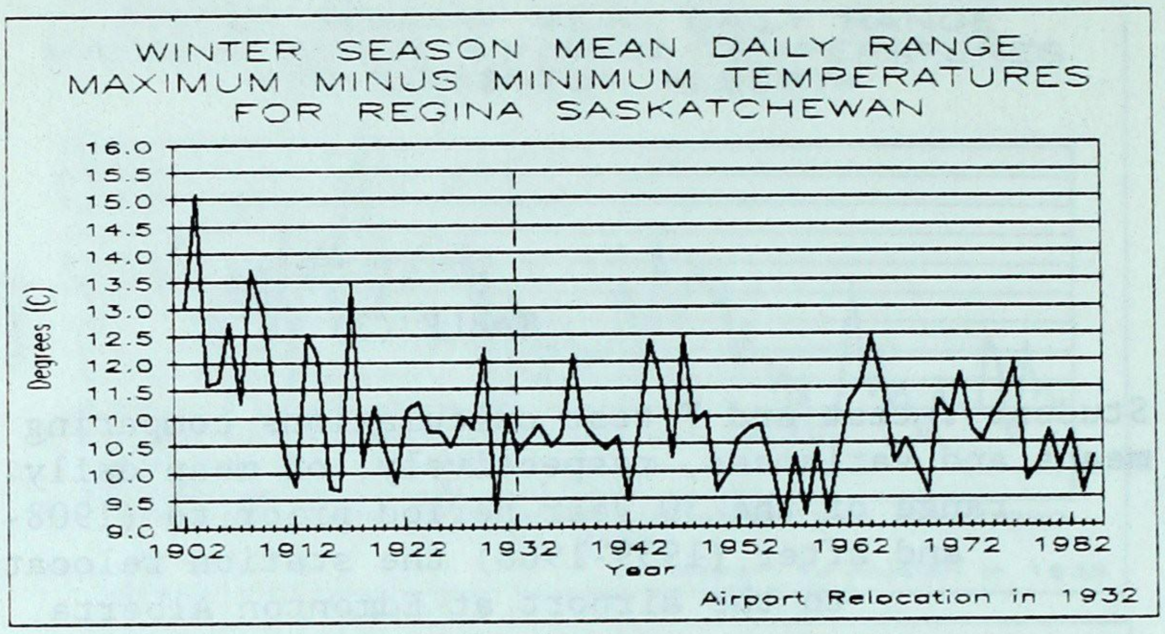
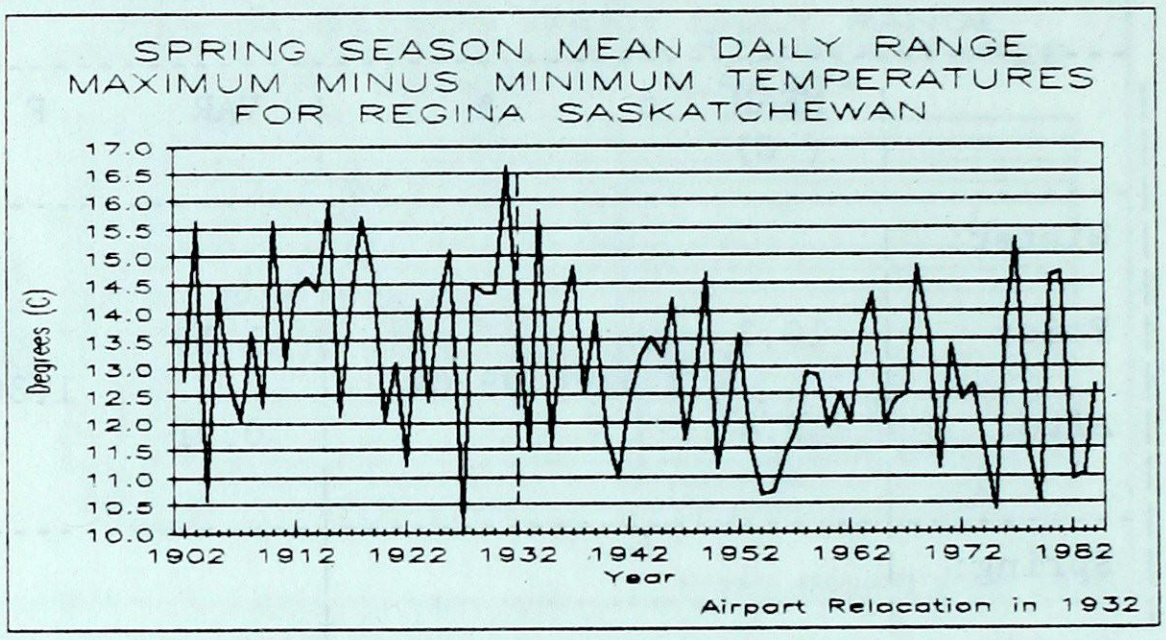

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Degrees (C)
Year
Airport Relocation in 1938

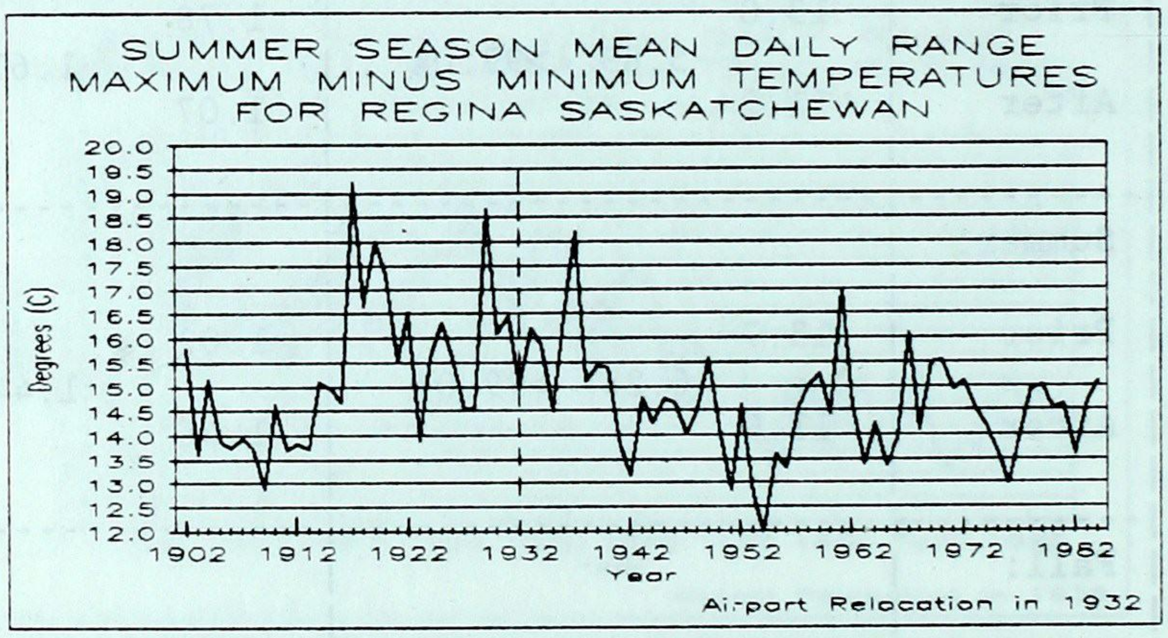
TABLE (3)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1908-1937) and after (1939-1968) the station relocation to the airport at Edmonton Alberta.

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	10.3	3.43	>99.0%	1.19	1.30	<90.0%
After	9.4			0.91		
Spring:						
Prior	13.0	5.89	>99.0%	1.78	1.67	<90.0%
After	11.2			1.07		
Summer:						
Prior	13.7	6.28	>99.0%	1.02	1.44	<90.0%
After	11.9			1.46		
Fall:						
Prior	12.0	4.27	>99.0%	1.80	1.53	<90.0%
After	10.7			1.17		


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1932


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1932


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1932

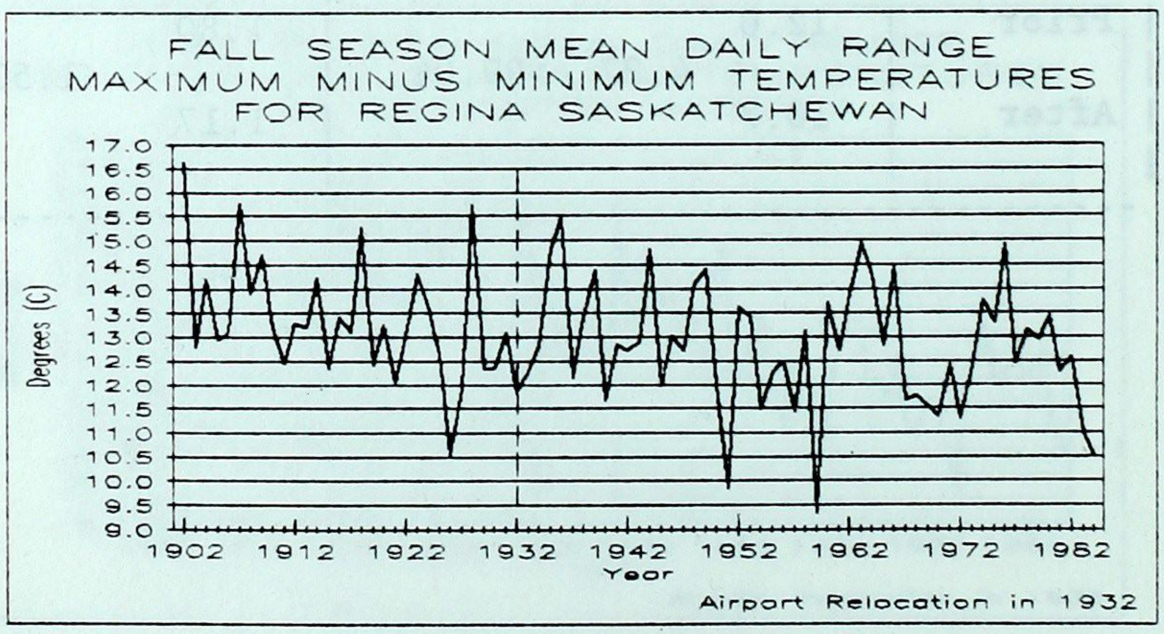
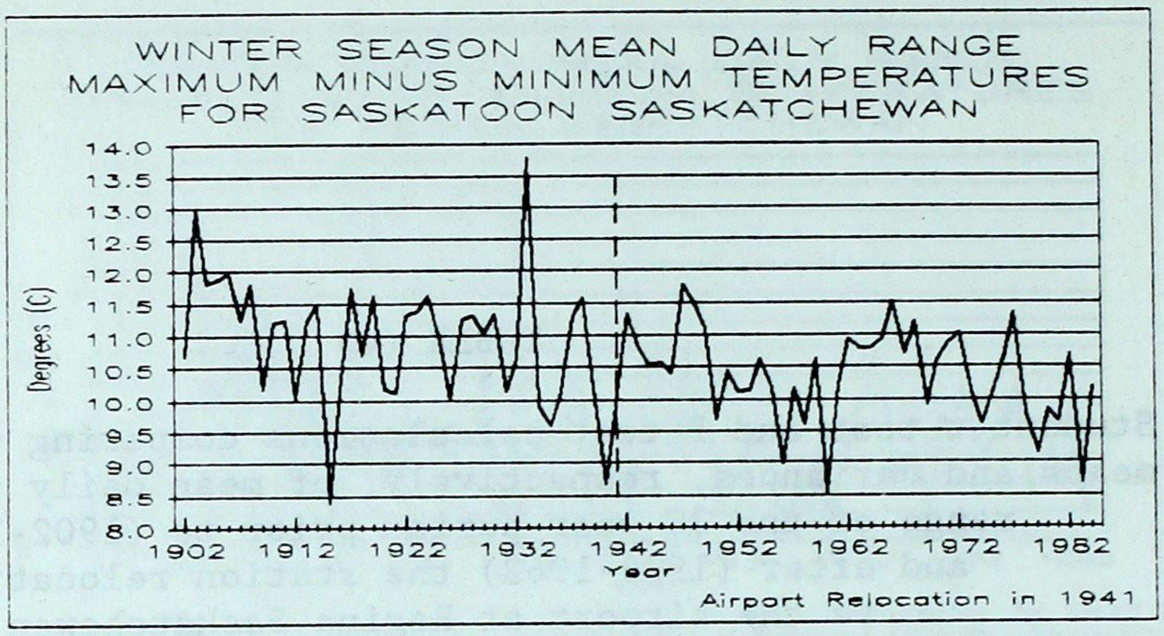
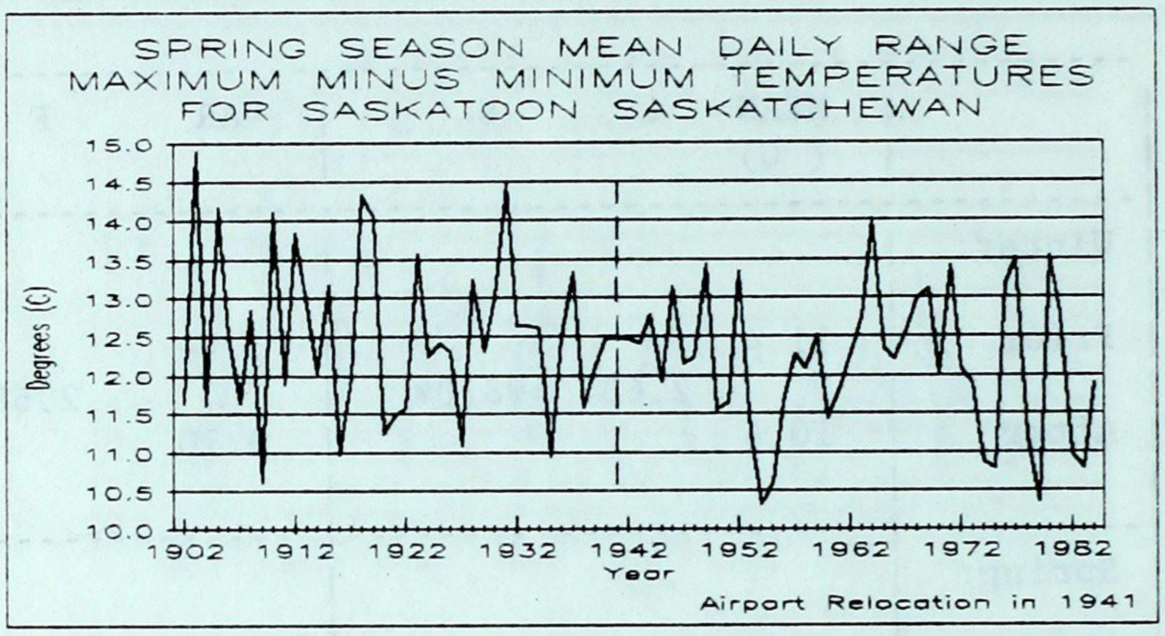

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1932

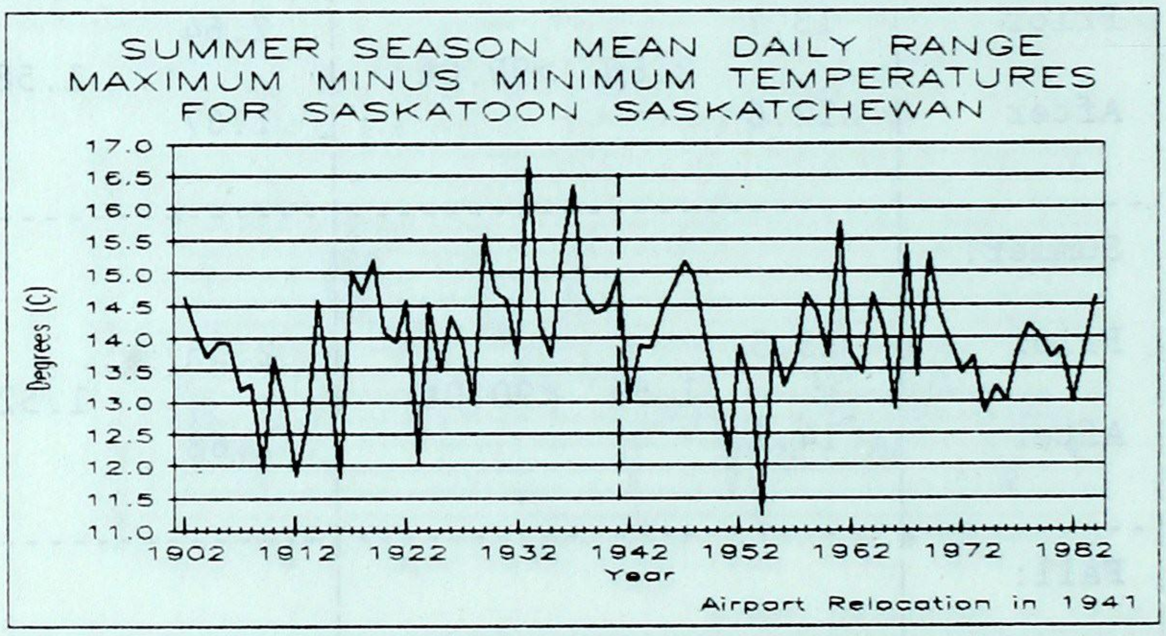
TABLE (4)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1902-1931) and after (1933-1962) the station relocation to the airport at Regina Saskatchewan

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	11.4	2.63	>98.0%	1.89	2.68	>99.0%
After	10.6			0.70		
Spring:						
Prior	13.7	2.66	>99.0%	2.64	1.58	<90.0%
After	12.6			1.67		
Summer:						
Prior	15.3	1.59	<90.0%	2.55	1.52	<90.0%
After	14.7			1.68		
Fall:						
Prior	13.4	1.55	<90.0%	1.68	1.10	<90.0%
After	12.8			1.85		


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1941


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1941


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1941

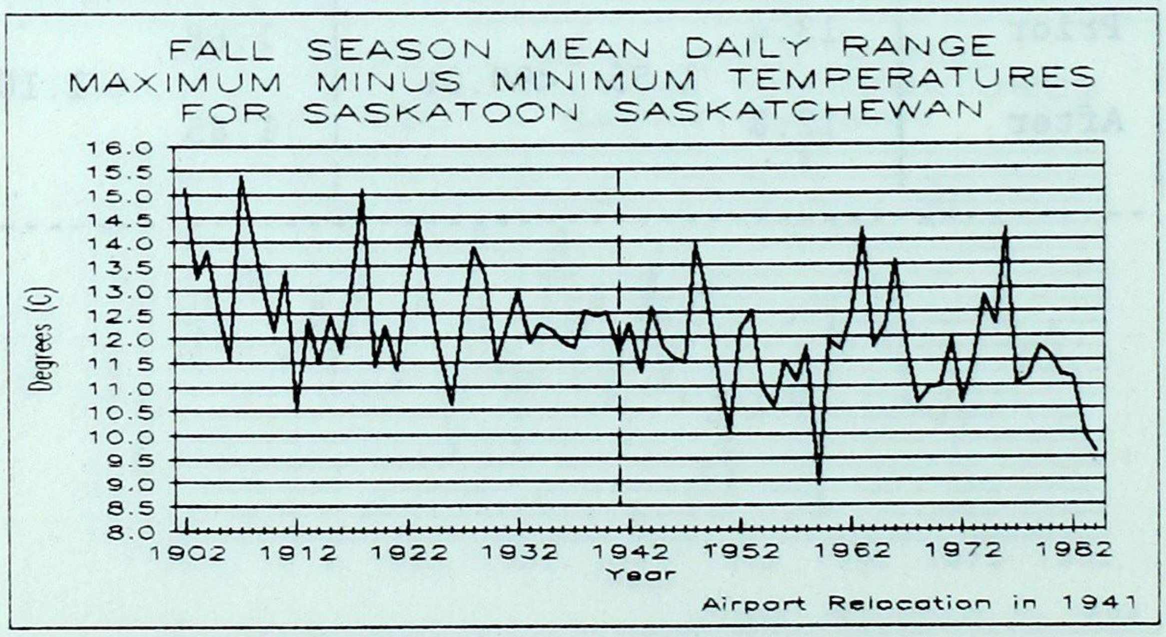
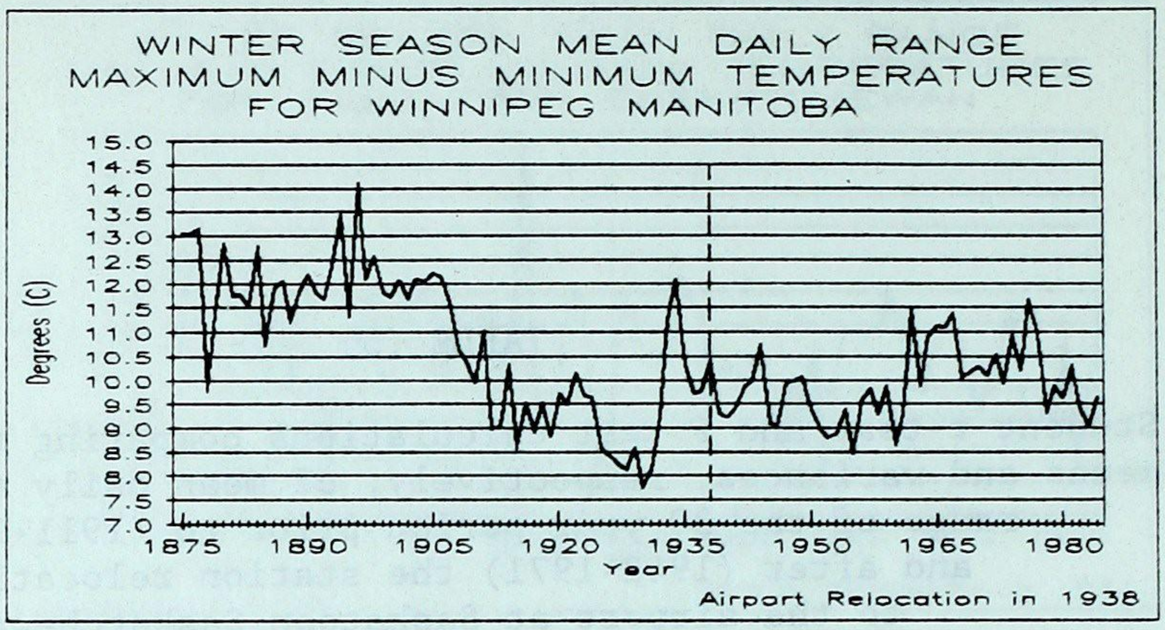

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Degrees (C)
Year
Airport Relocation in 1941

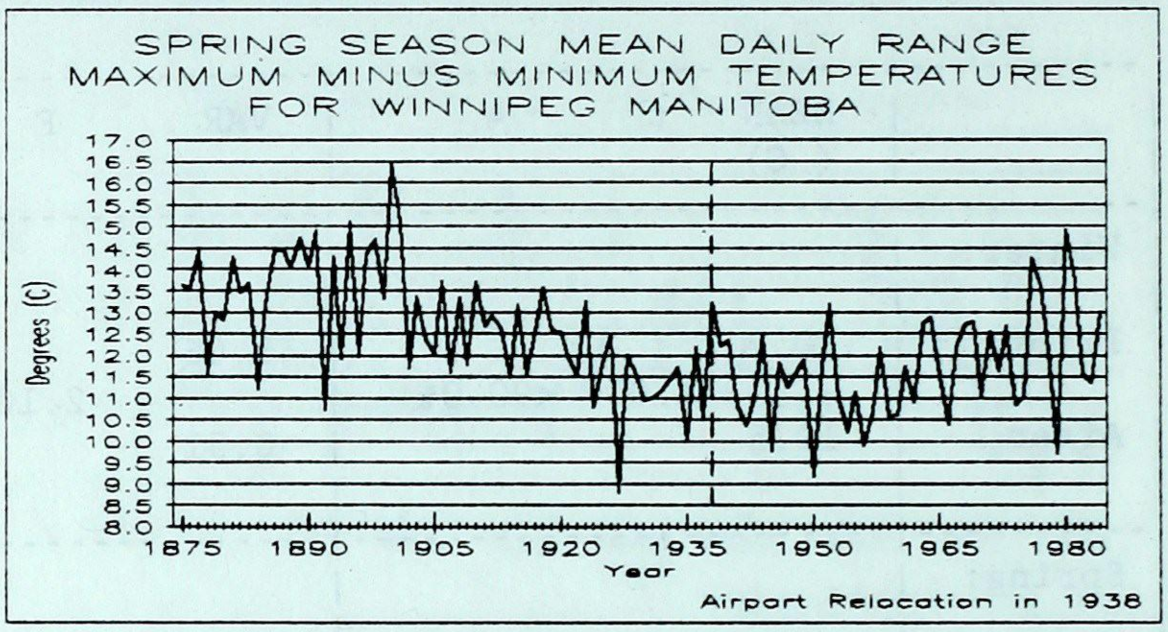
TABLE (5)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1911-1940) and after (1942-1971) the station relocation to the airport at Saskatoon Saskatchewan

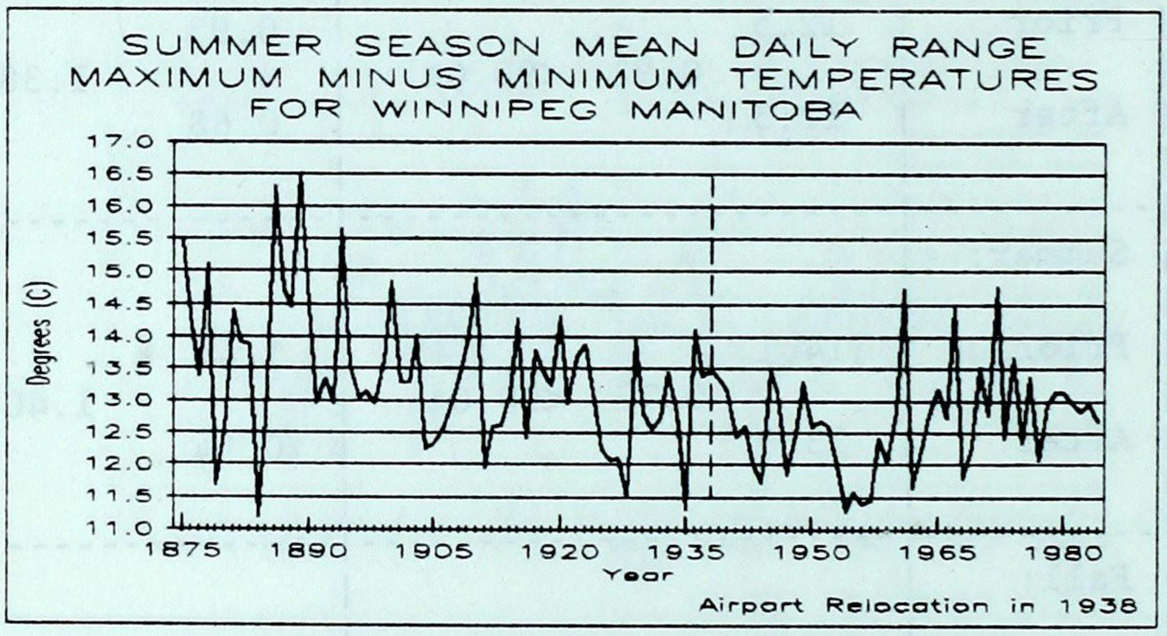
	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	10.7	1.03	<90.0%	1.06	2.10	>97.5%
After	10.5			0.51		
Spring:						
Prior	12.5	0.92	<90.0%	0.93	1.38	<90.0%
After	12.3			0.68		
Summer:						
Prior	14.1	0.72	<90.0%	1.40	1.40	<95.0%
After	13.9			0.94		
Fall:						
Prior	12.4	2.32	>95.0%	1.04	1.10	<95.0%
After	11.7			1.20		



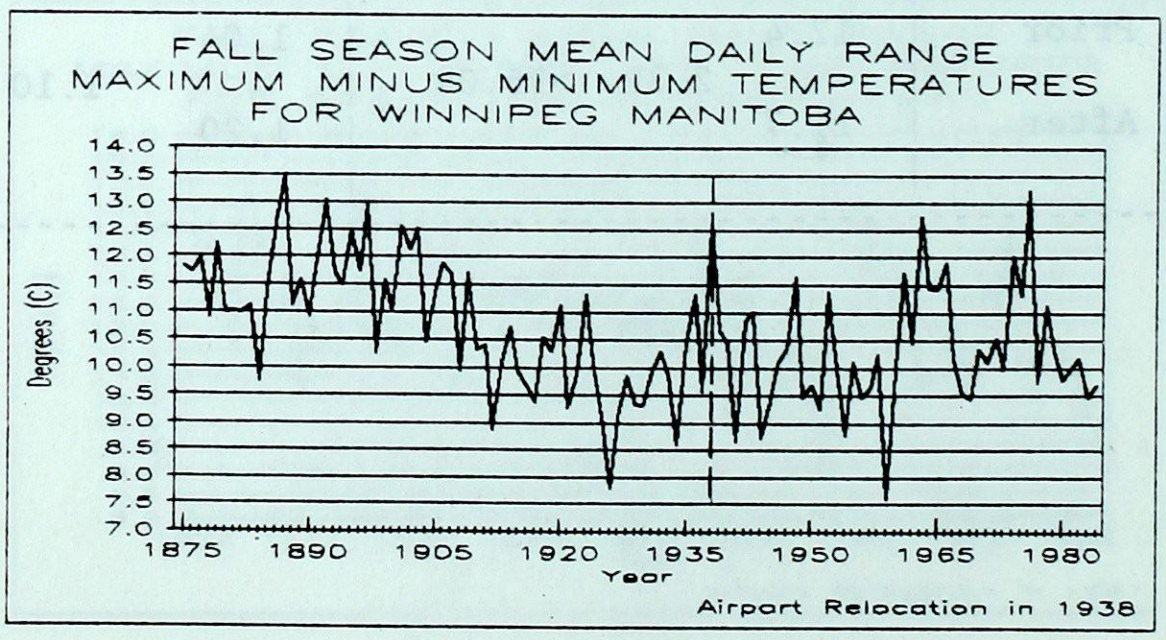
WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA



SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA



SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA

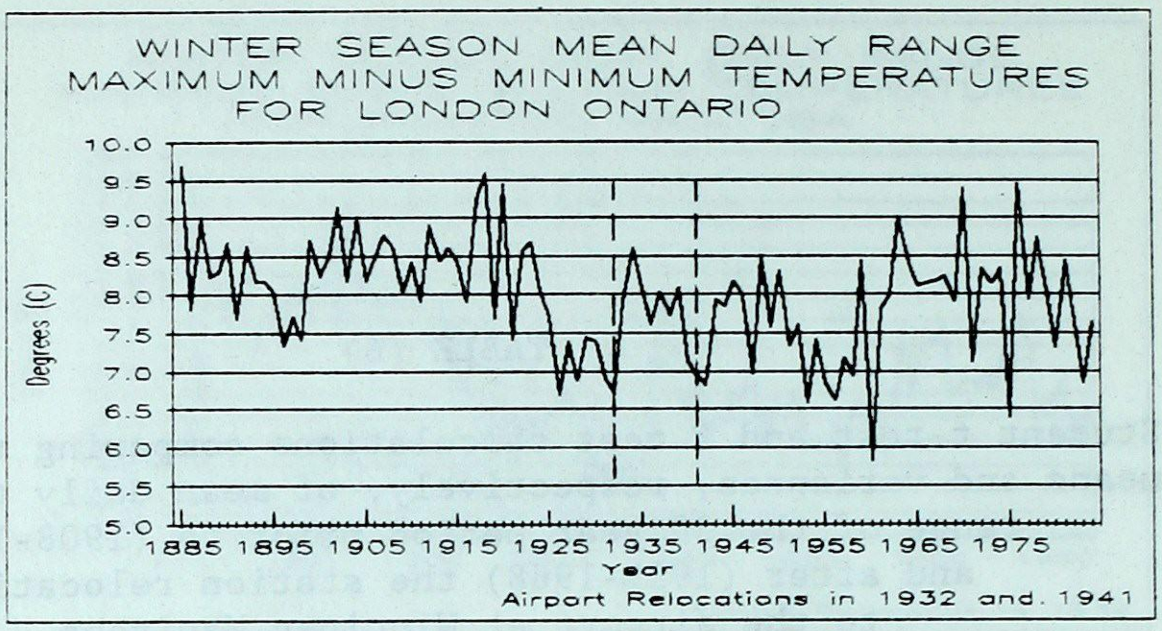


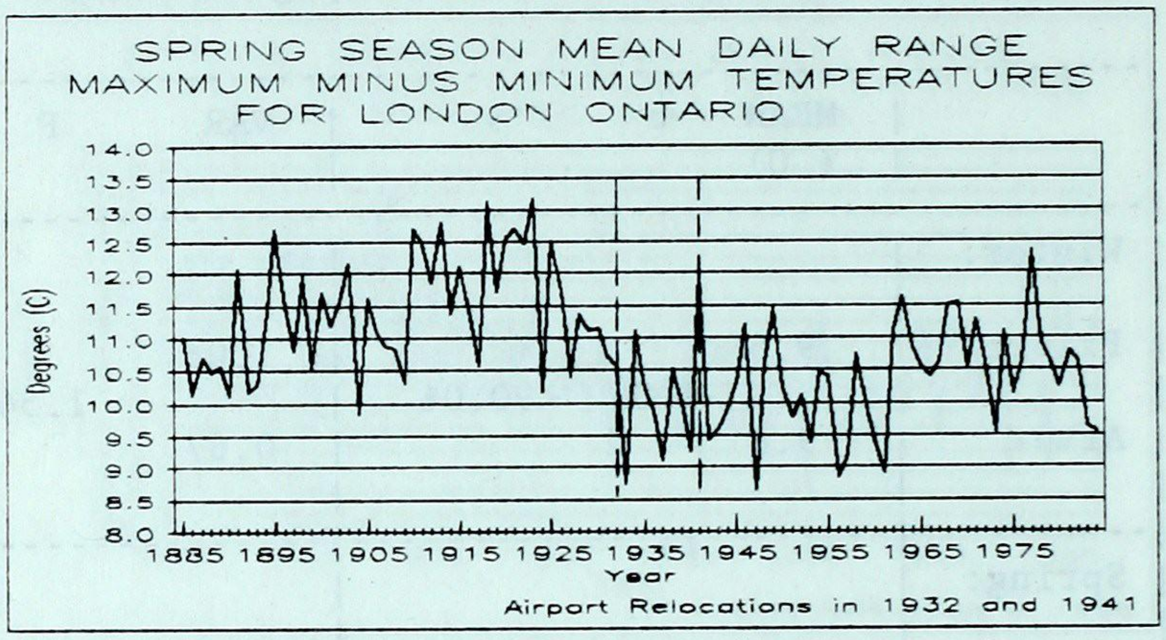
FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA

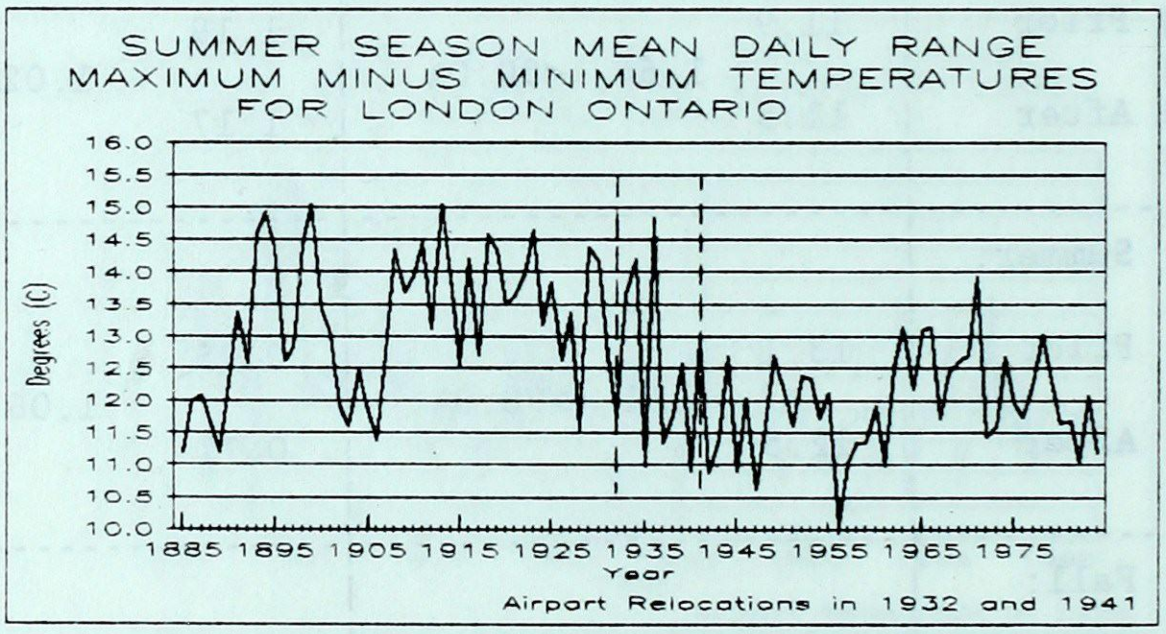
TABLE (6)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1908-1937) and after (1939-1968) the station relocation to the airport at Winnipeg Manitoba.

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	9.5	-1.07	<90.0%	1.03	1.54	<95.0%
After	9.8			0.67		
Spring:						
Prior	11.9	1.64	<90.0%	1.19	1.02	<95.0%
After	11.5			1.17		
Summer:						
Prior	13.1	2.51	>98.0%	0.75	1.06	<95.0%
After	12.5			0.71		
Fall:						
Prior	9.9	-1.13	<90.0%	0.72	1.74	<95.0%
After	10.2			1.25		


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Degrees (C)
Year
Airport Relocations in 1932 and 1941


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Degrees (C)
Year
Airport Relocations in 1932 and 1941


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Degrees (C)
Year
Airport Relocations in 1932 and 1941

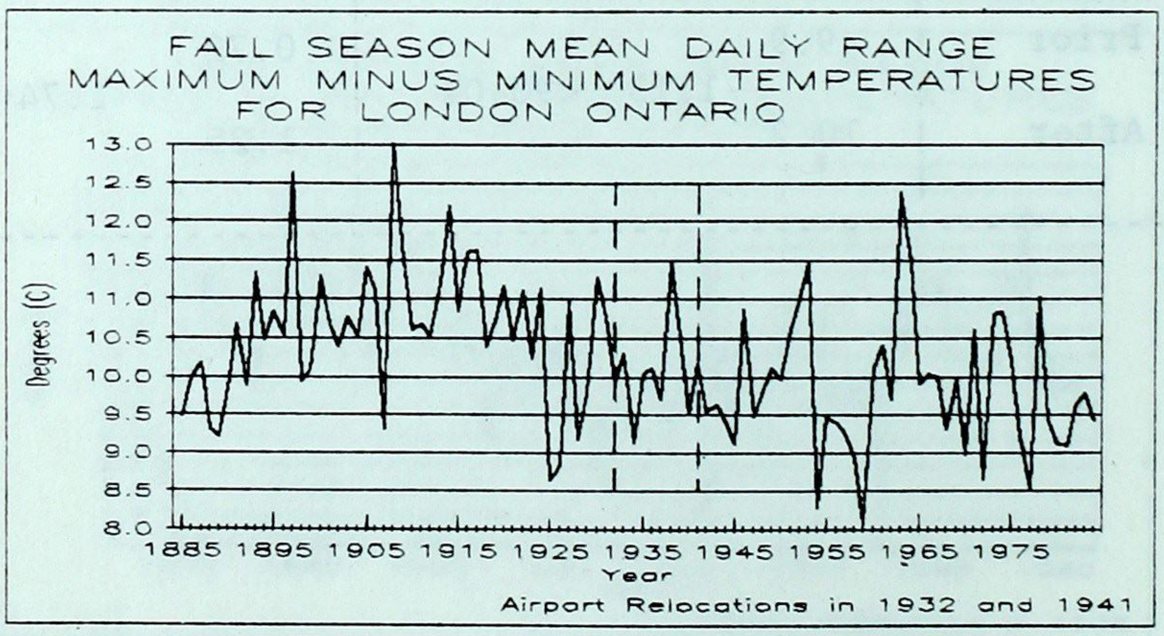
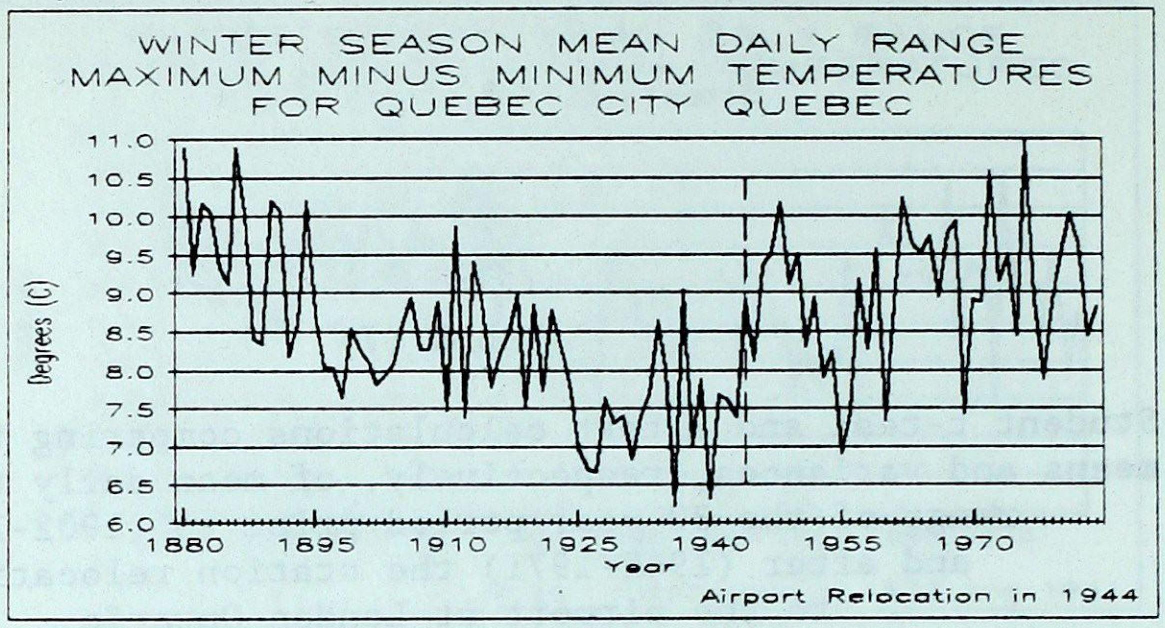
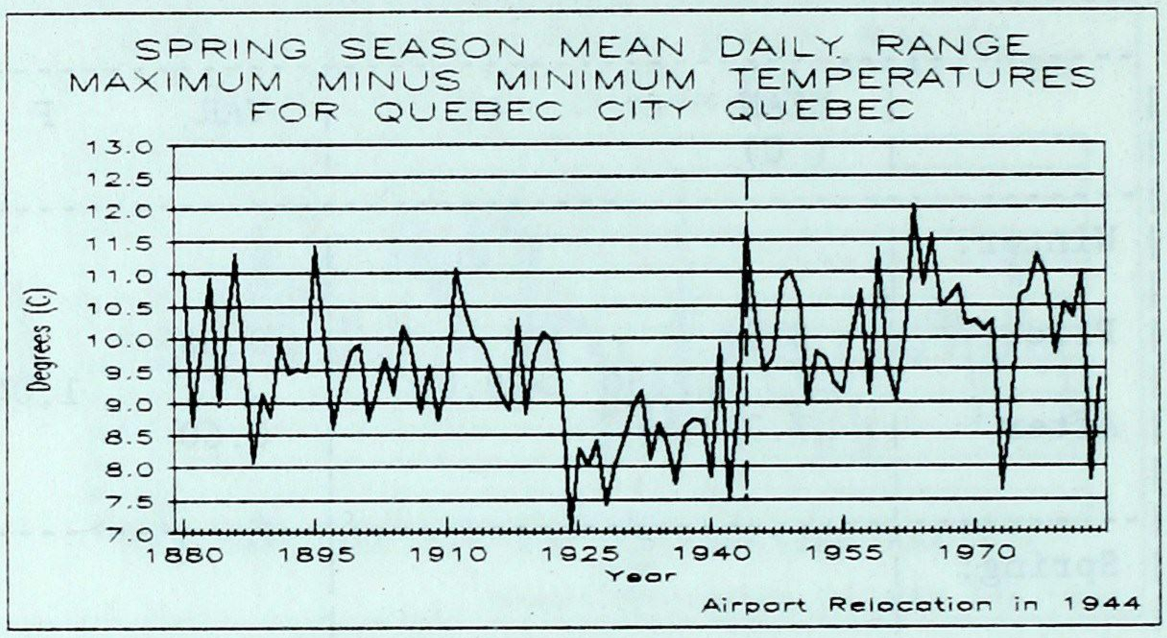

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Degrees (C)
Year
Airport Relocations in 1932 and 1941

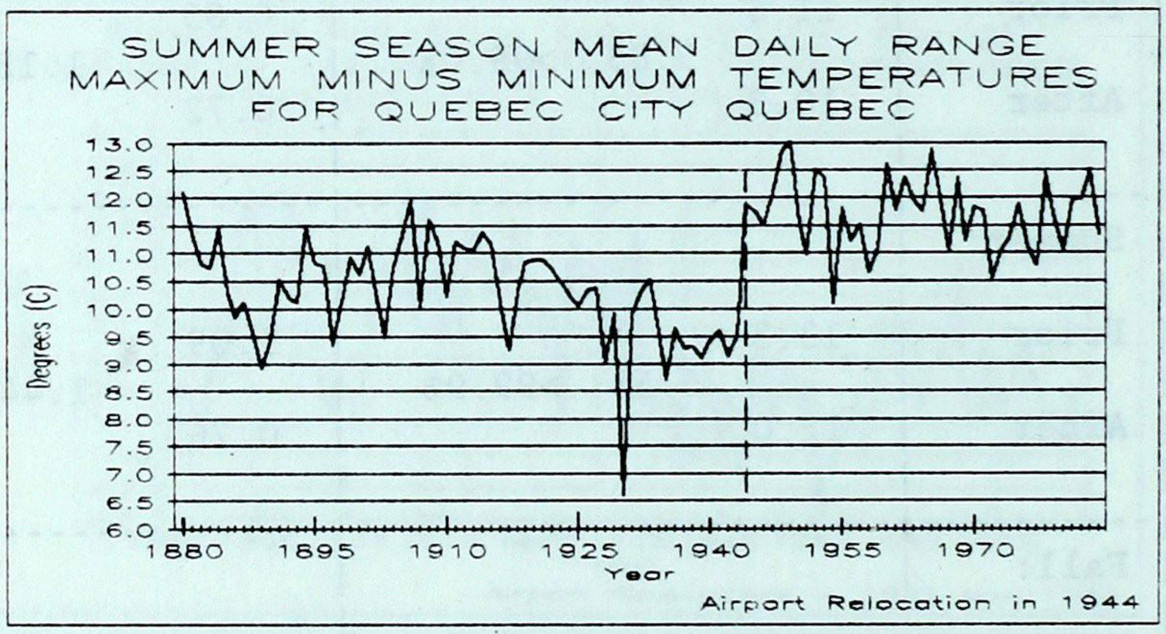
TABLE (7)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1902-1931) and after (1942-1971) the station relocation to the airport at London Ontario.

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	8.2	2.50	>99.0%	0.58	1.04	<95.0%
After	7.7			0.60		
Spring:						
Prior	11.6	5.83	>99.0%	0.85	1.18	<95.0%
After	10.3			0.72		
Summer:						
Prior	13.3	5.53	>99.9%	1.09	1.44	<95.0%
After	12.0			0.76		
Fall:						
Prior	10.7	3.42	>99.9%	0.87	1.01	<95.0%
After	9.9			0.86		


WINTER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Degrees (C)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
1880
1895
1910
1925
1940
1955
1970
Year
Airport Relocation in 1944


SPRING SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Degrees (C)
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
1880
1895
1910
1925
1940
1955
1970
Year
Airport Relocation in 1944


SUMMER SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Degrees (C)
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
1880
1895
1910
1925
1940
1955
1970
Year
Airport Relocation in 1944

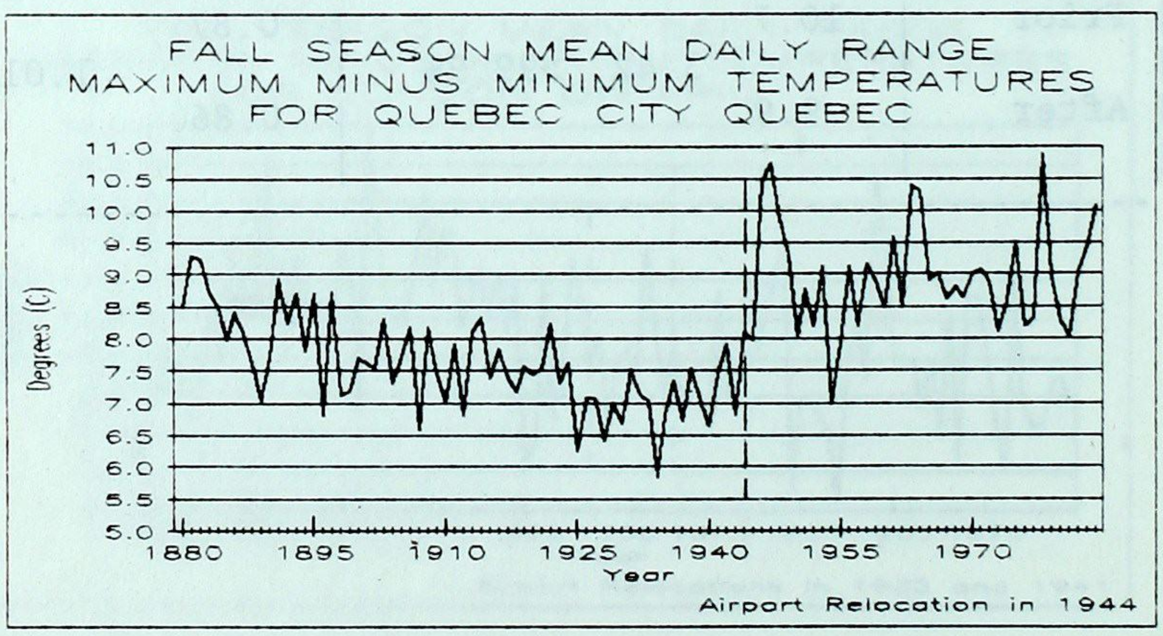

FALL SEASON MEAN DAILY RANGE
MAXIMUM MINUS MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Degrees (C)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1880
1895
1910
1925
1940
1955
1970
Year
Airport Relocation in 1944

TABLE (8)

Student t-test and F test calculations comparing the seasonal means and variances, respectively, of mean daily temperature range of the 30 year period prior to (1914-1943) and after (1945-1974) the station relocation to the airport at Quebec City Quebec.

	MEAN (C)	t	%	VAR	F	%
Winter:						
Prior	7.7			0.62		
		-5.57	>99.9%		1.40	<95.0%
After	9.0			0.86		
Spring:						
Prior	8.7			0.73		
		-5.77	>99.9%		1.18	<95.0%
After	10.1			0.86		
Summer:						
Prior	9.9			0.86		
		-8.49	>99.9%		1.63	<95.0%
After	11.7			0.53		
Fall:						
Prior	7.2			0.30		
		-9.34	>99.9%		2.33	>97.5%
After	8.9			0.71		

APPENDIX II

Figure (11) to Figure (24) - Seasonal base-tau difference maximum and minimum temperature time series' for the seven base stations.

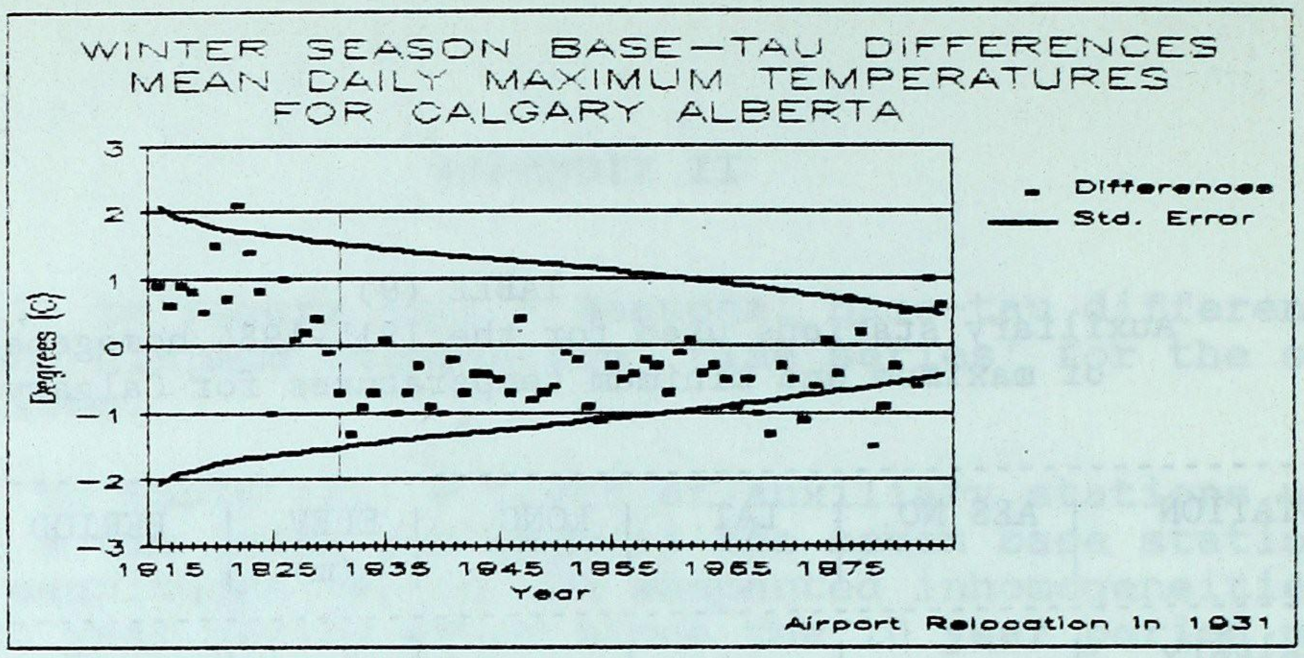
Table (9) to Table (22) - Lists of auxiliary stations used to obtain a tau index for each of the seven base stations. Seasonal magnitudes (M) of the suspected inhomogeneities for the 10 year period after minus the 10 year period prior to an airport relocation.

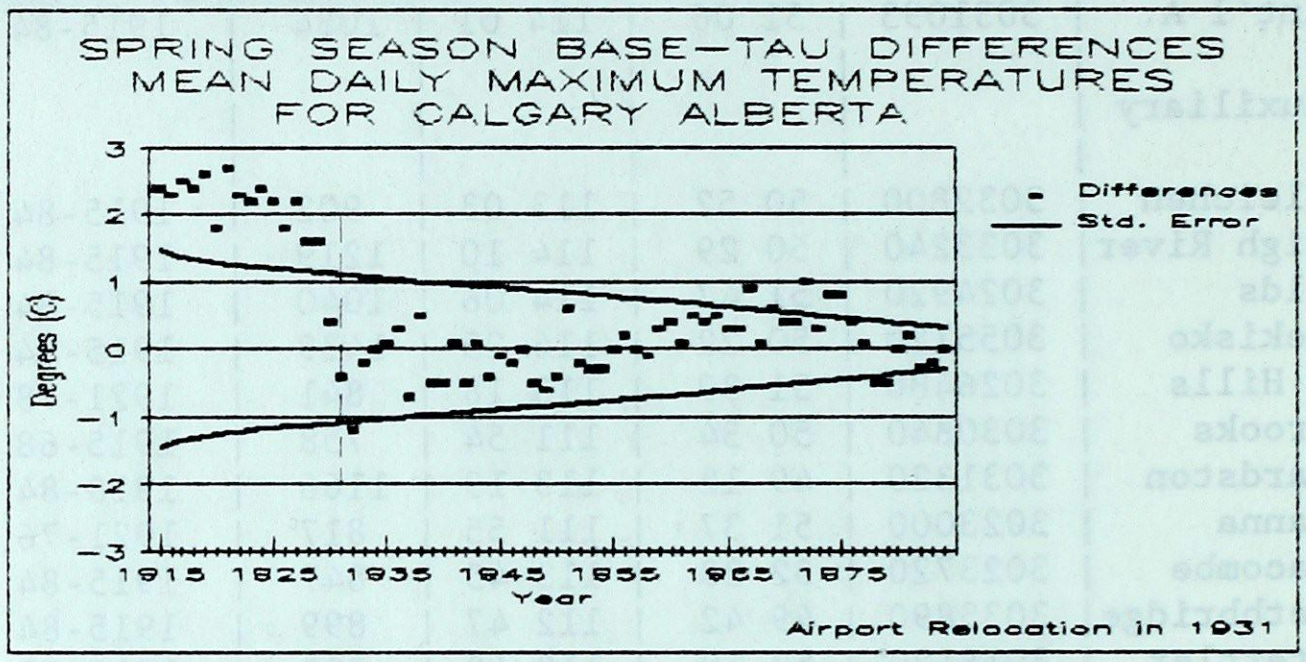
TABLE (9)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Calgary Alberta

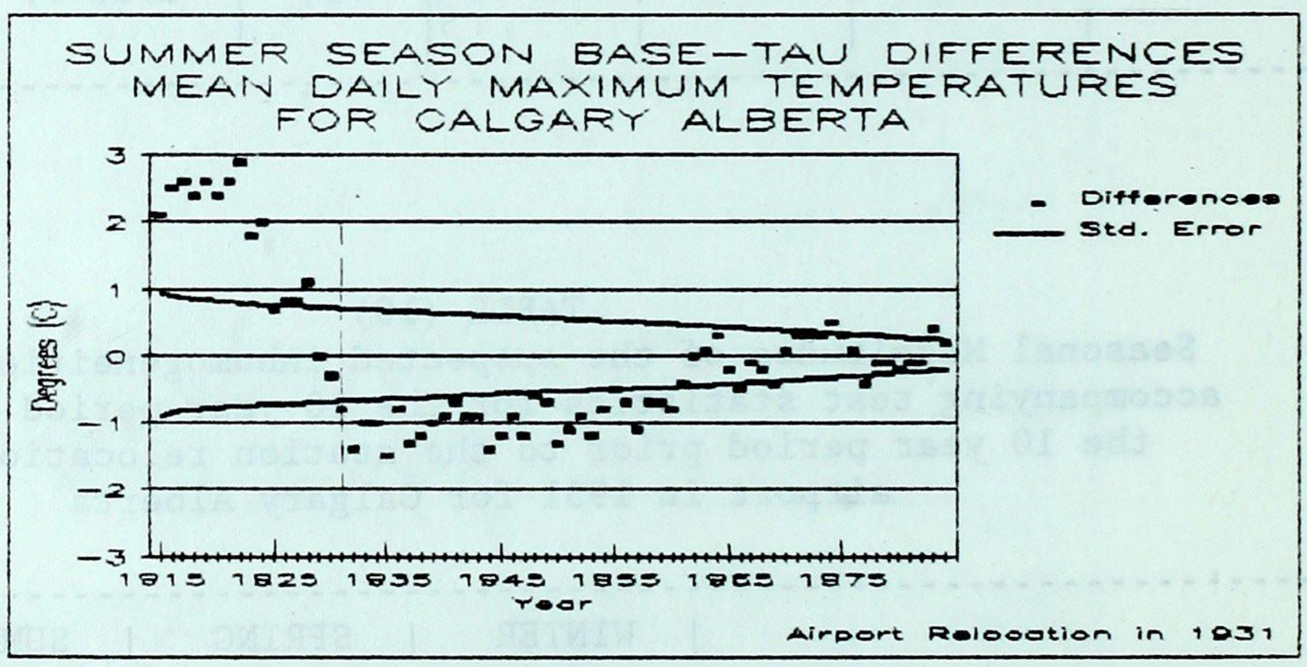
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Calgary Int'l A.	3031093	51 06	114 01	1084	1915-84	Airport(1931)
Auxiliary						
Gleichen	3032800	50 52	113 03	902	1915-84	7
High River	3033240	50 29	114 10	1219	1915-84	7
Olds	3024920	51 47	114 06	1040	1915-84	2
Pekisko	3055120	50 22	114 25	1439	1915-84	2
3 Hills	3026480	51 39	113 18	841	1921-78	2
Brooks	3030840	50 34	111 54	758	1915-68	0
Cardston	3031320	49 12	113 19	1166	1918-84	3
Hanna	3023000	51 37	111 55	817	1921-76	6
Lacombe	3023720	52 28	113 45	847	1915-84	0
Lethbridge	3033890	49 42	112 47	899	1915-84	1
Stettler	3016120	52 19	112 42	823	1918-77	1

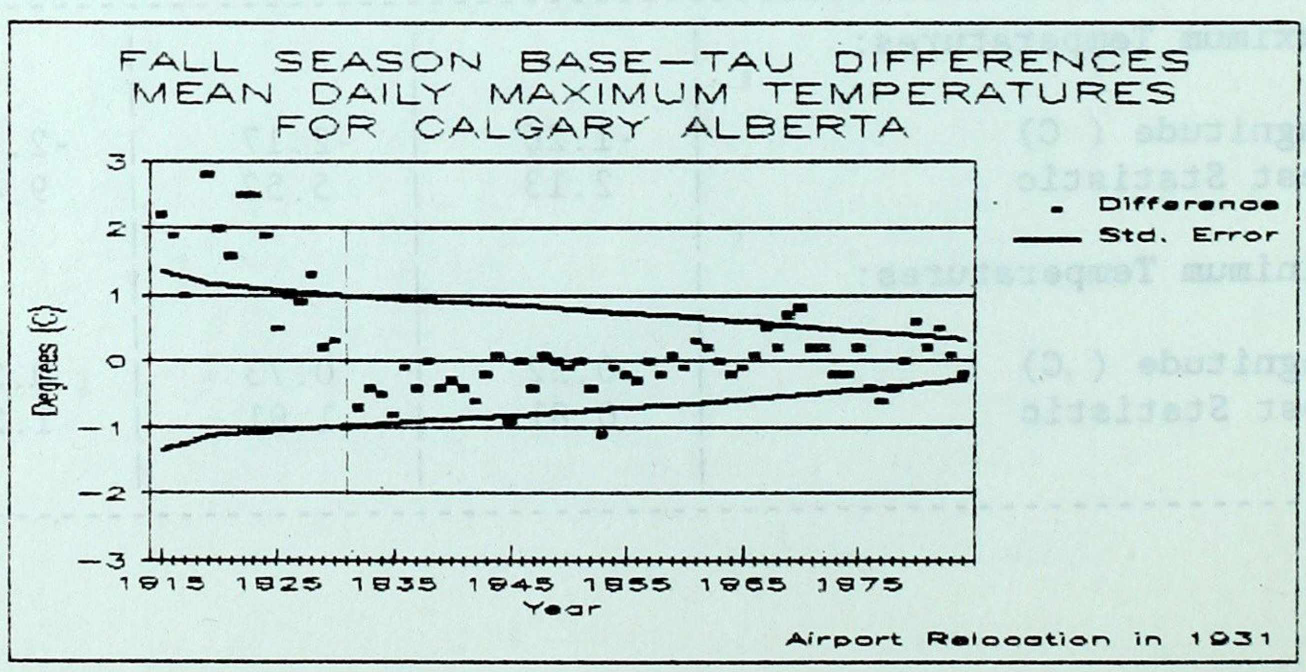
TABLE (10)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1931 for Calgary Alberta

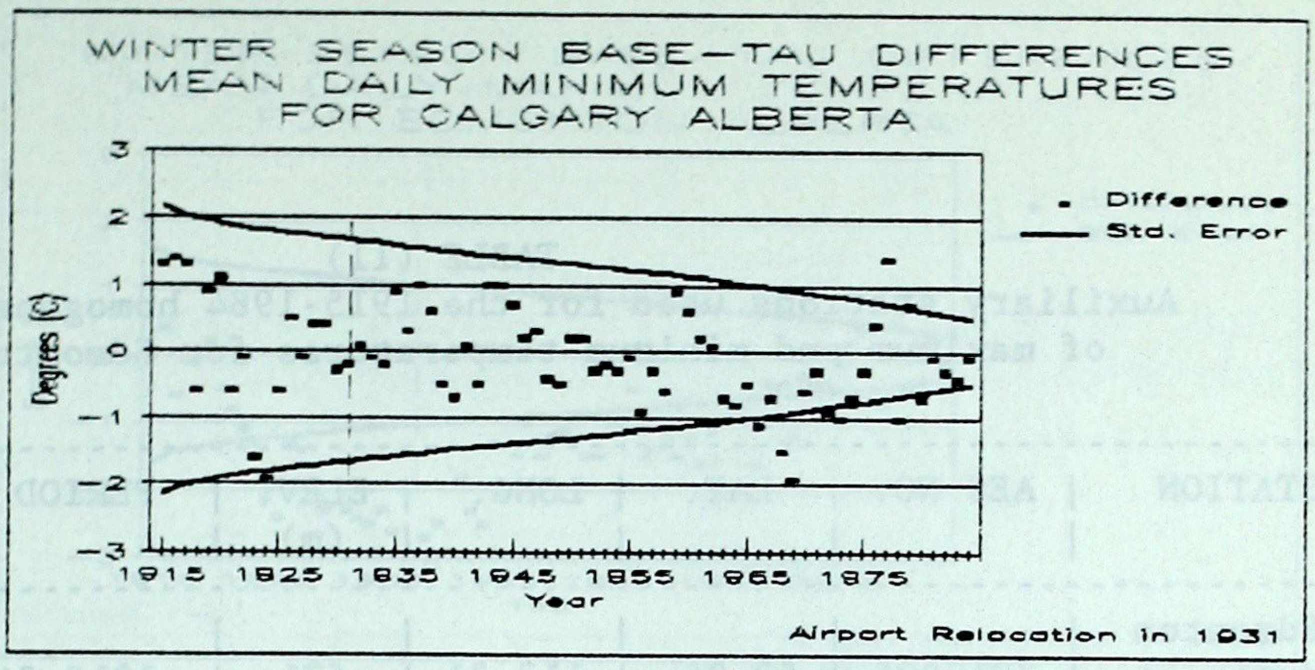
	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-1.26	-2.17	-2.29	-1.66
Test Statistic	2.13	5.52	9.46	4.68
Minimum Temperatures:				
Magnitude (C)	0.52	0.73	0.25	0.42
Test Statistic	0.81	1.91	1.23	1.25

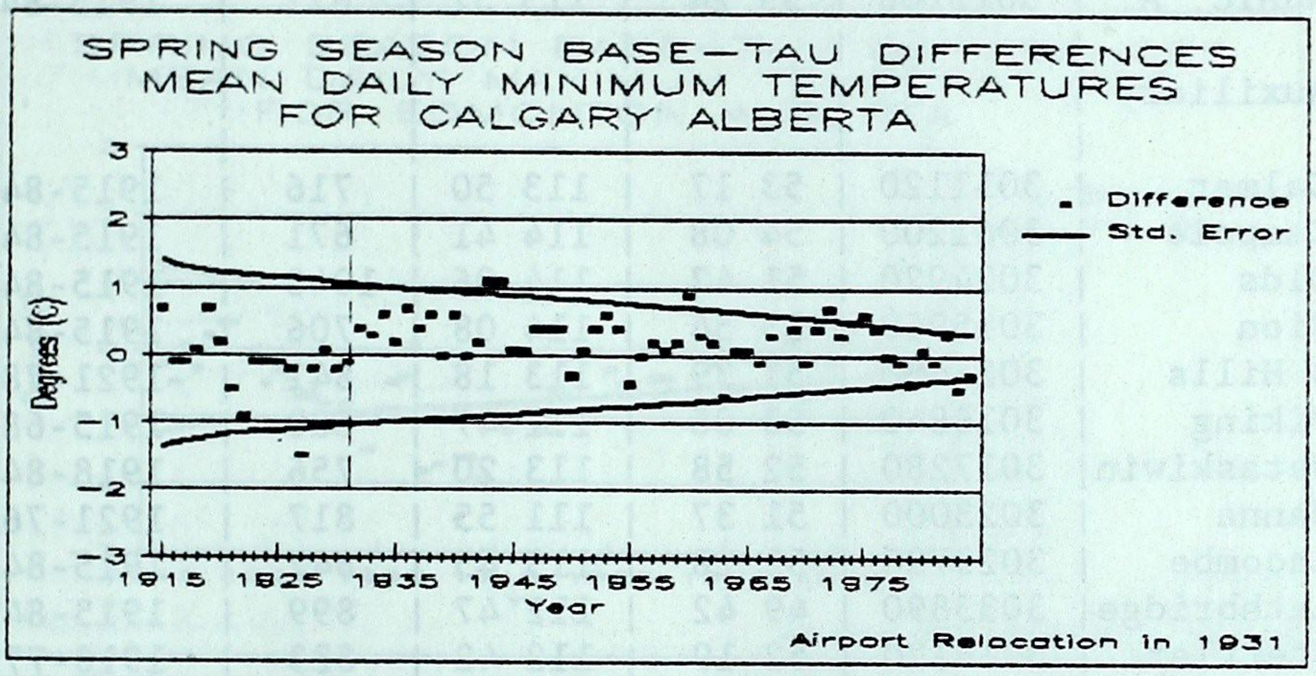

WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR CALGARY ALBERTA
Differences
Std. Error
Degrees (C)
1915 1925 1935 1945 1955 1965 1875
Year
Airport Relocation in 1931

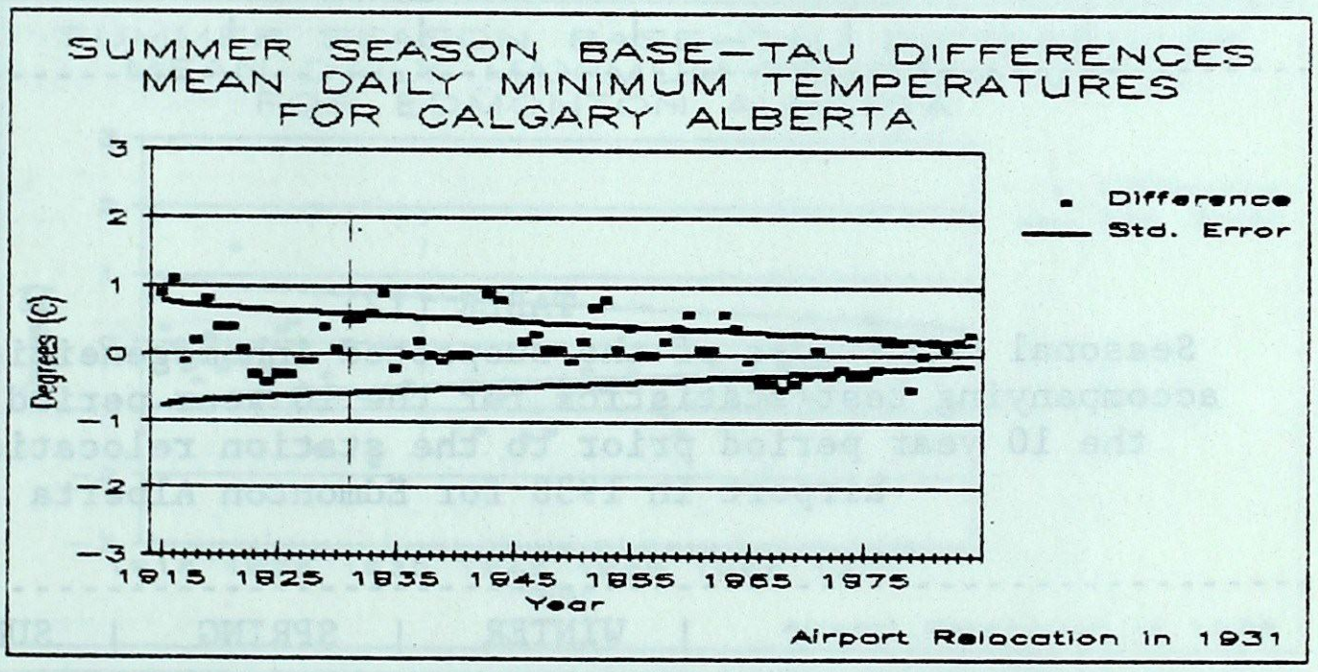

SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR CALGARY ALBERTA
Differences
Std. Error
Degrees (C)
Year
Airport Relocation in 1931


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR CALGARY ALBERTA
Differences
Std. Error
Degrees (C)
Year
Airport Relocation in 1931


FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR CALGARY ALBERTA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1931


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1931


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1931


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1931

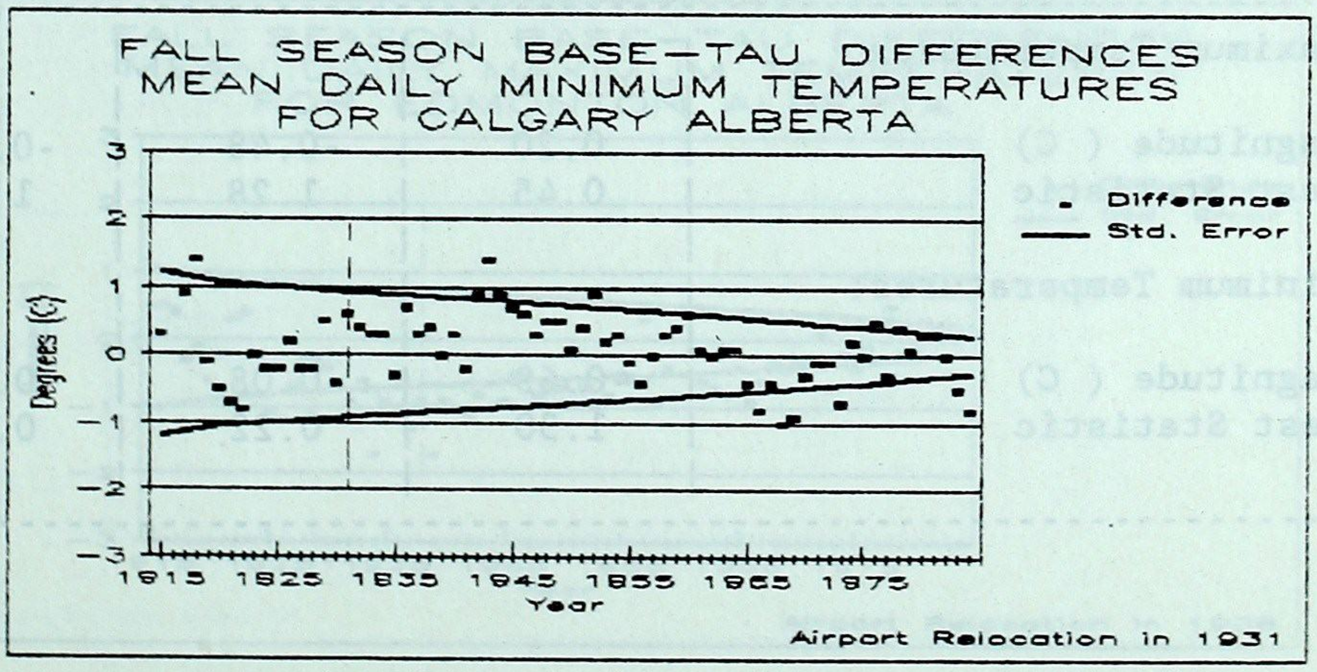
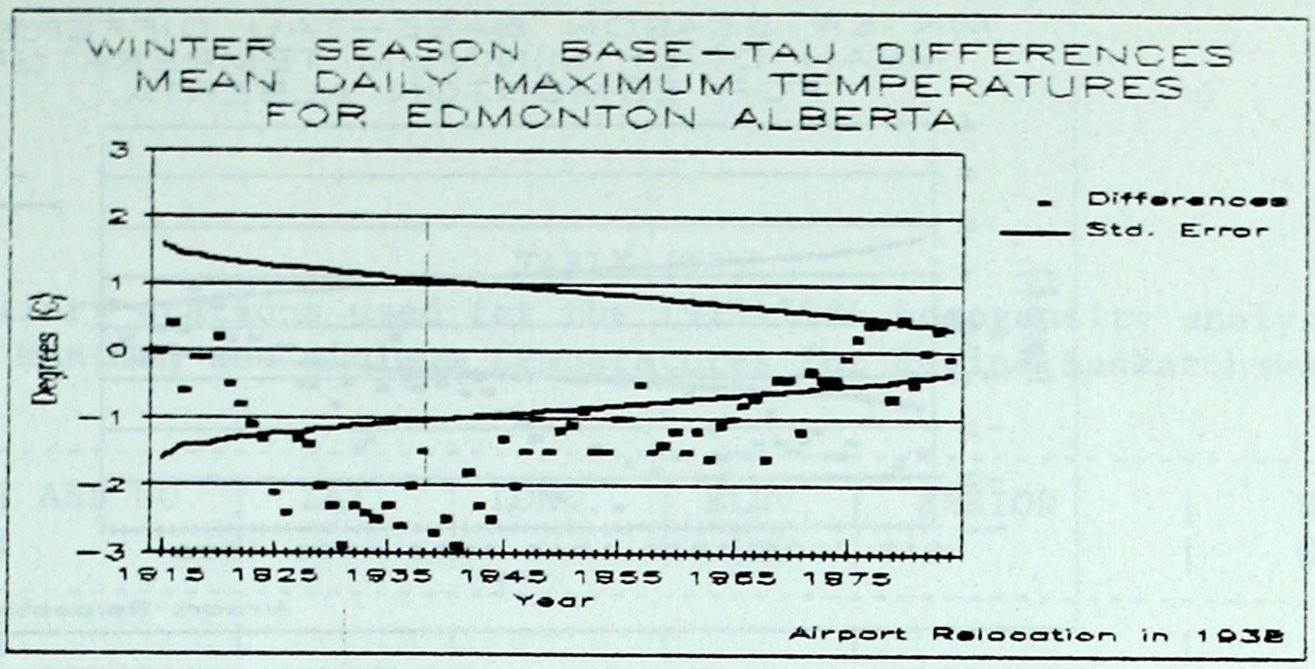

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR CALGARY ALBERTA
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1931

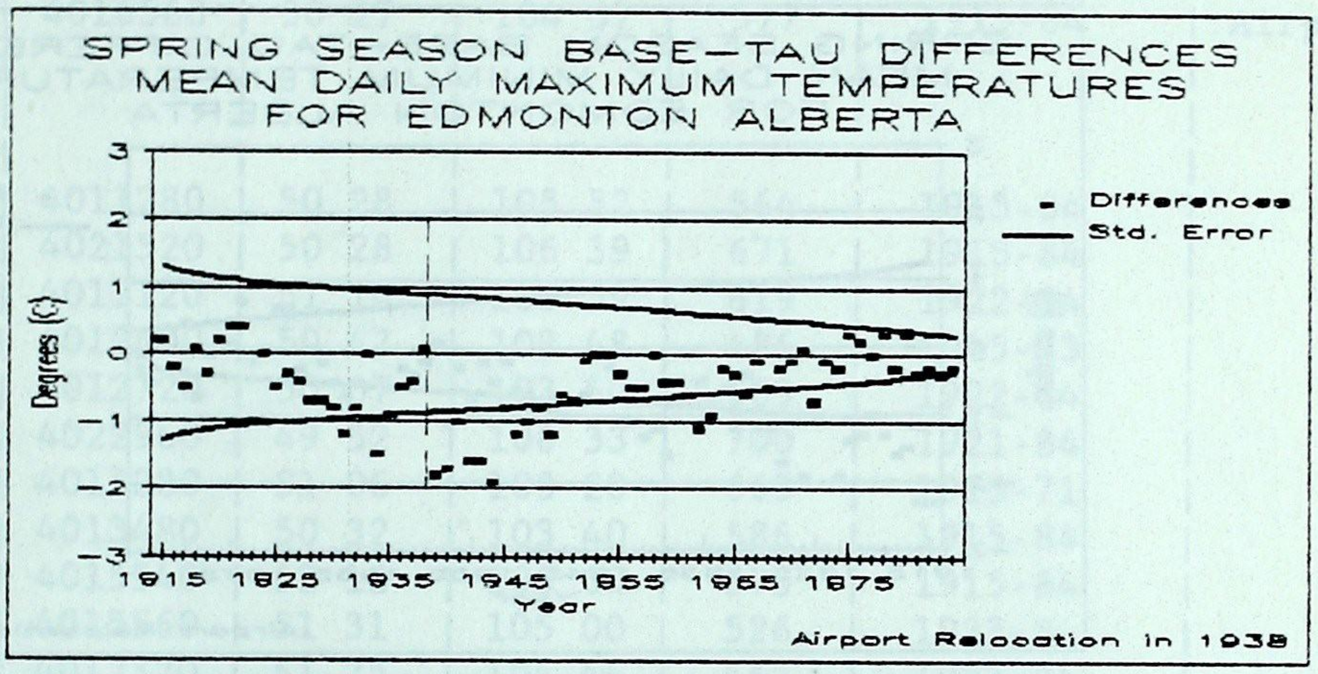
TABLE (11)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Edmonton Alberta

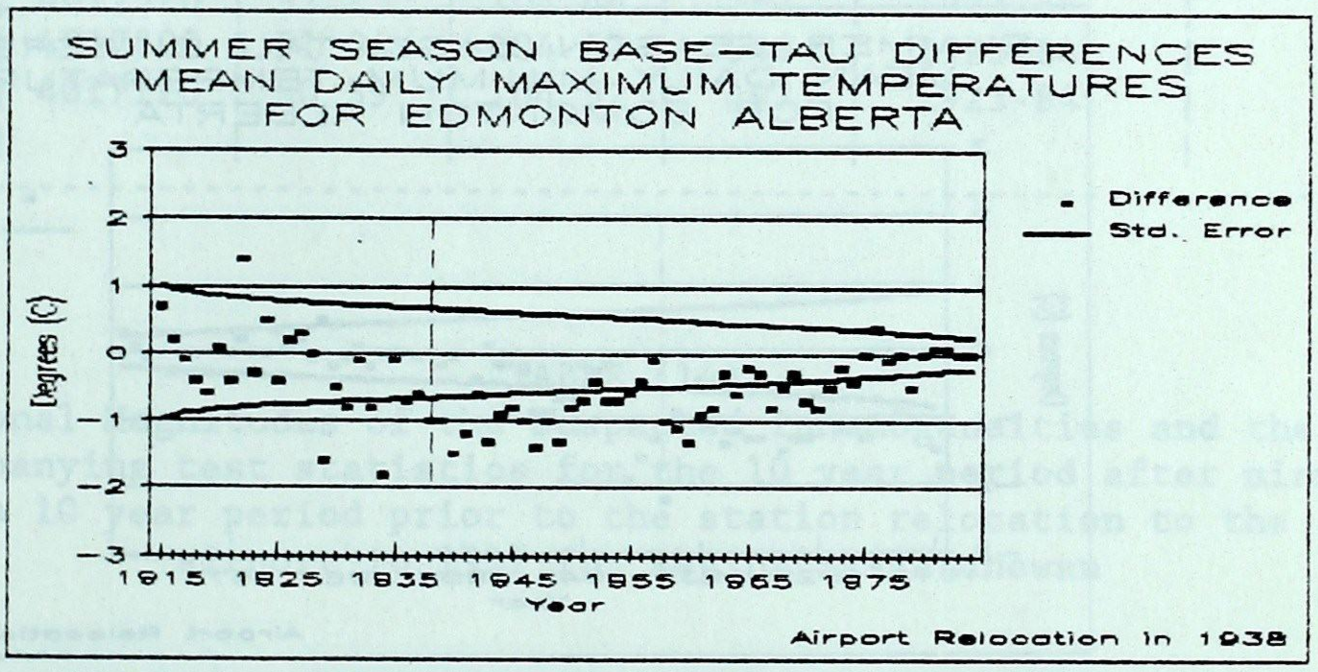
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Edmonton Munic. A.	3012208	53 24	113 31	671	1915-84	Airport(1938)
Auxiliary						
Calmar	3011120	53 17	113 50	716	1915-84	2
Campsie	3061200	54 08	114 41	671	1915-84	2
Olds	3024920	51 47	114 06	1040	1915-84	2
Sion	3015960	53 54	114 08	706	1915-84	4
3 Hills	3026480	51 39	113 18	841	1921-78	2
Viking	3016840	53 06	111 47	680	1915-68	0
Wetaskiwin	3017280	52 58	113 20	756	1918-84	0
Hanna	3023000	51 37	111 55	817	1921-76	6
Lacombe	3023720	52 28	113 45	847	1915-84	0
Lethbridge	3033890	49 42	112 47	899	1915-84	1
Stettler	3016120	52 19	112 42	823	1918-77	1

TABLE (12)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1938 for Edmonton Alberta

	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	0.20	-0.48	-0.38	-0.14
Test Statistic	0.45	1.28	1.35	0.48
Minimum Temperatures:				
Magnitude (C)	-0.63	-0.08	0.12	-0.13
Test Statistic	1.30	0.22	0.49	0.44


WINTER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Differences
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915
1925
1935
1945
1955
1965
1975
Year
Airport Relocation in 1938


SPRING SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Differences
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915
1925
1935
1945
1955
1965
1975
Year
Airport Relocation in 1938


SUMMER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
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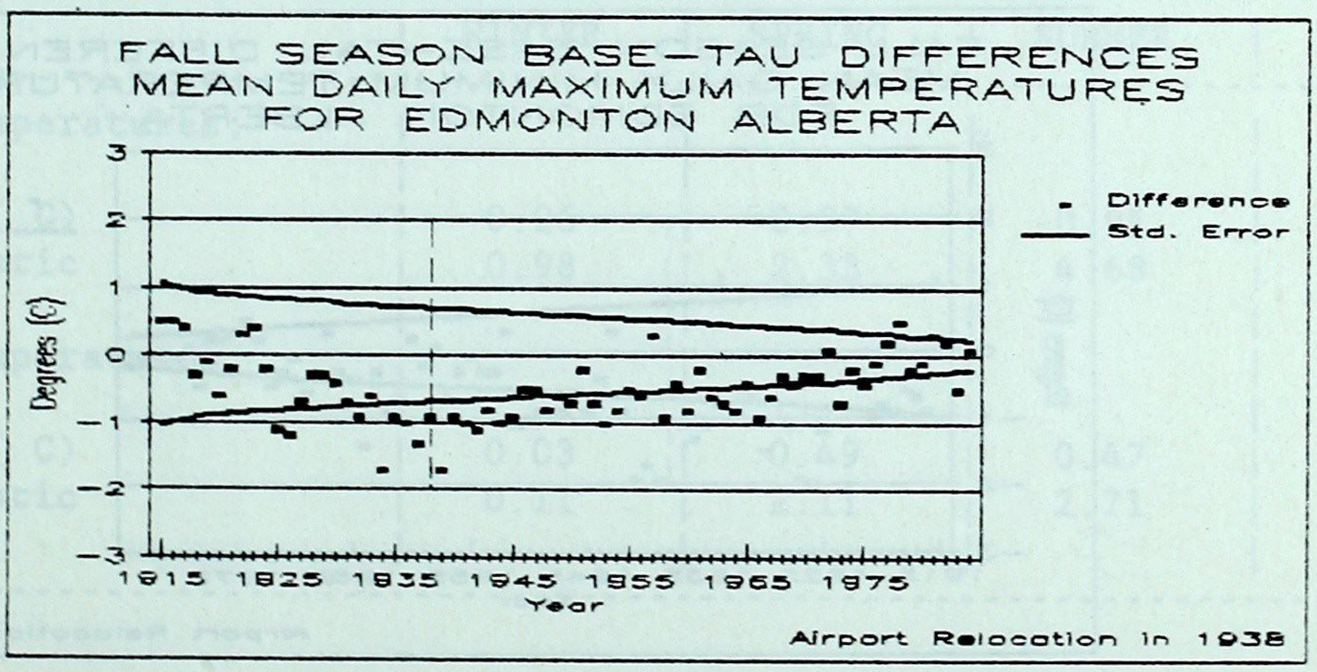
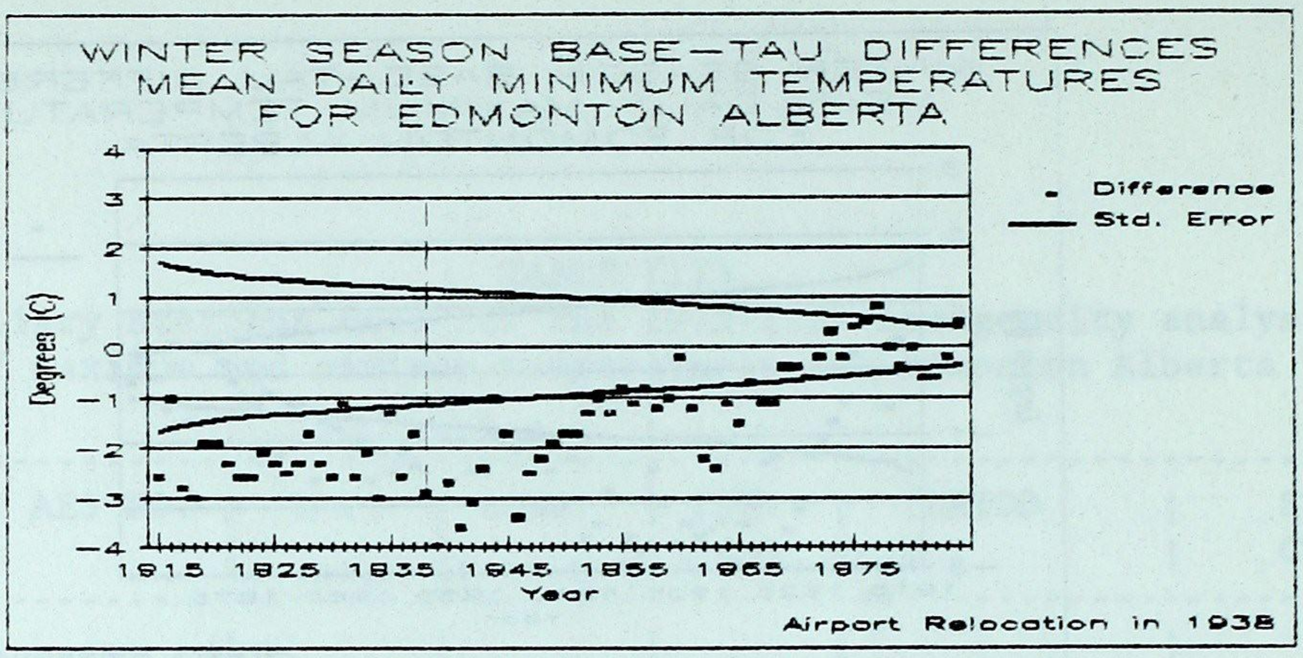
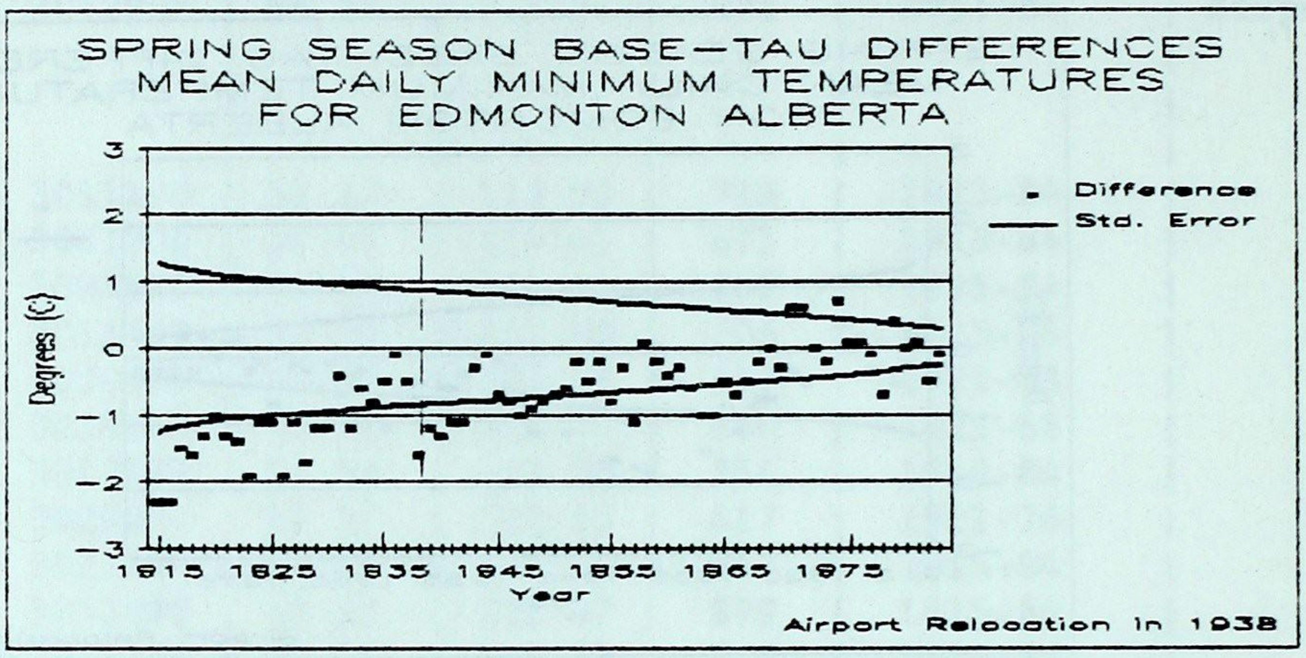
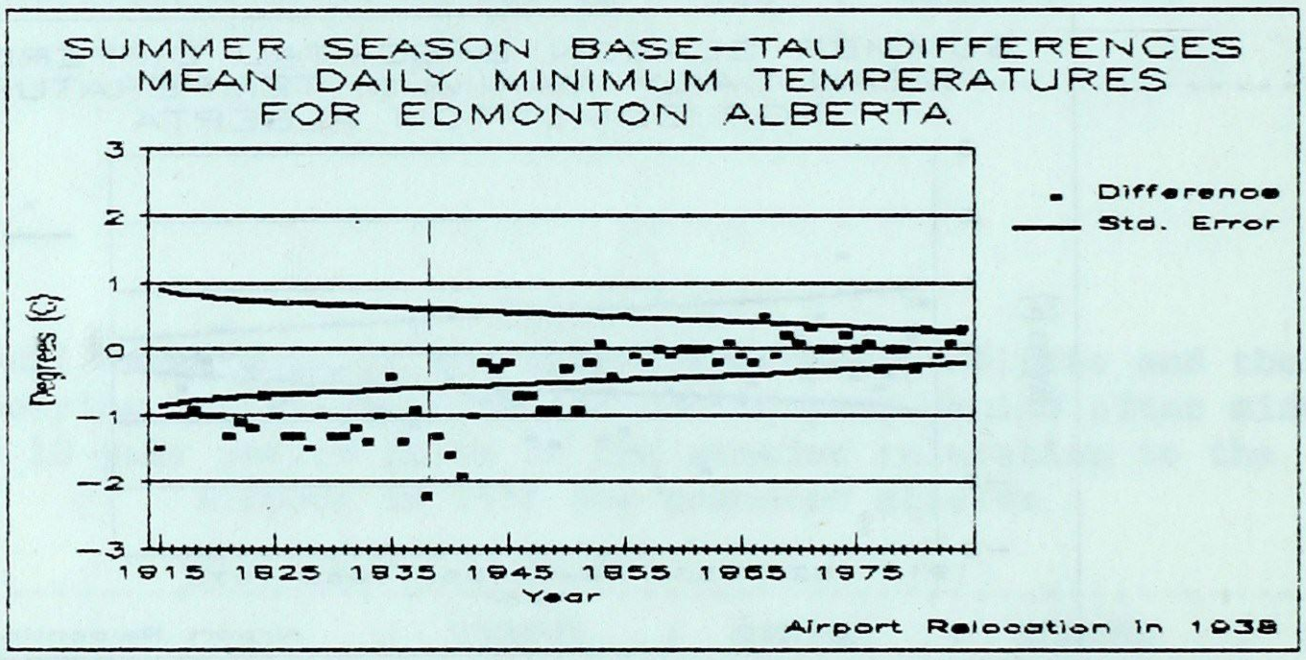
2
1
0
−1
−2
−3
1915
1925
1935
1945
1955
1965
1975
Year
Airport Relocation in 1938


FALL SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915
1925
1935
1945
1955
1965
1975
Year
Airport Relocation in 1938


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938

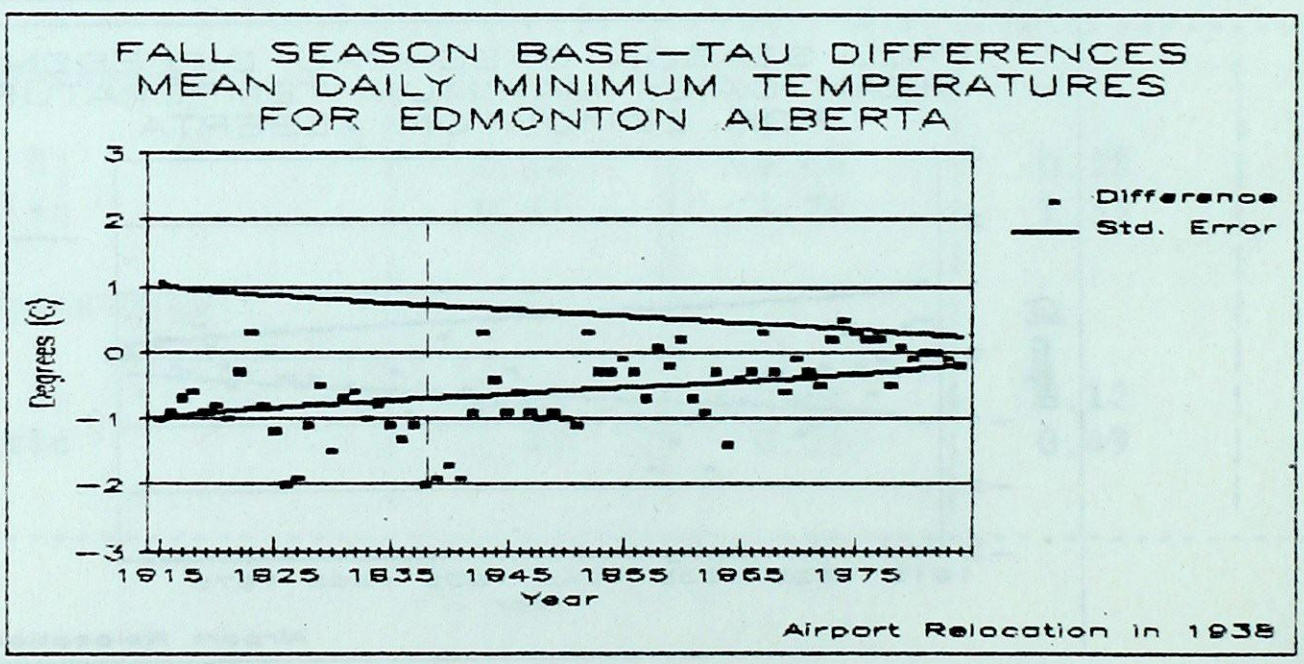
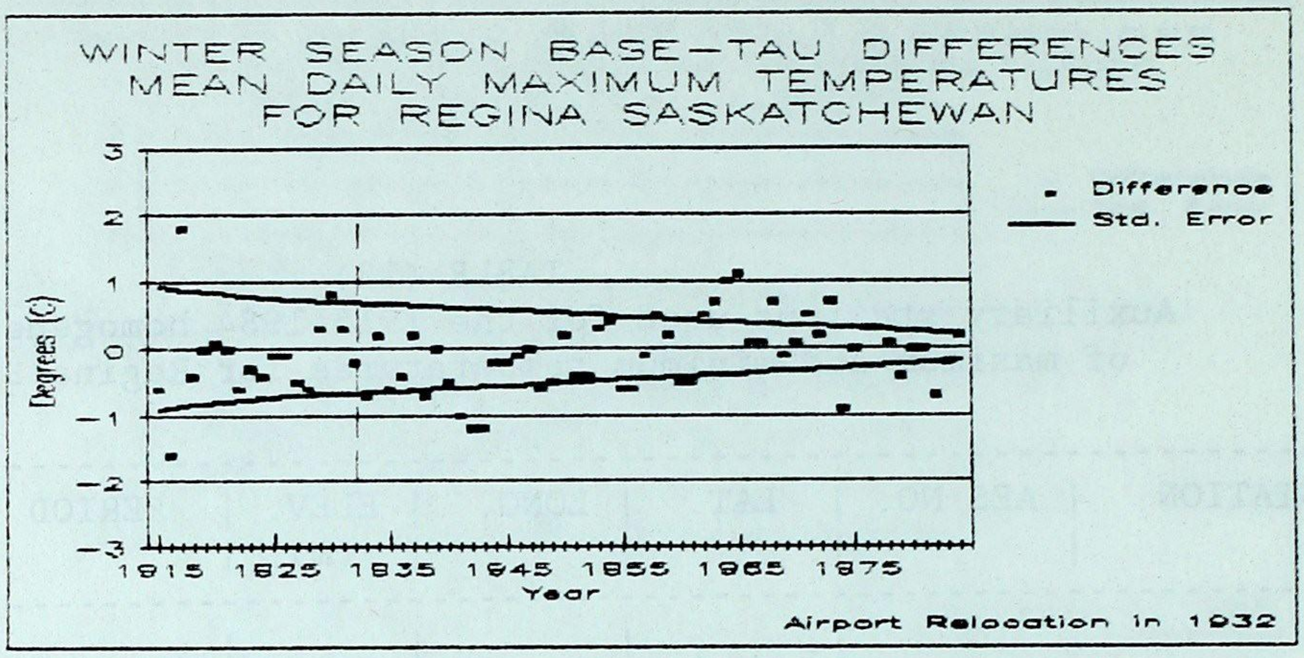

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR EDMONTON ALBERTA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938

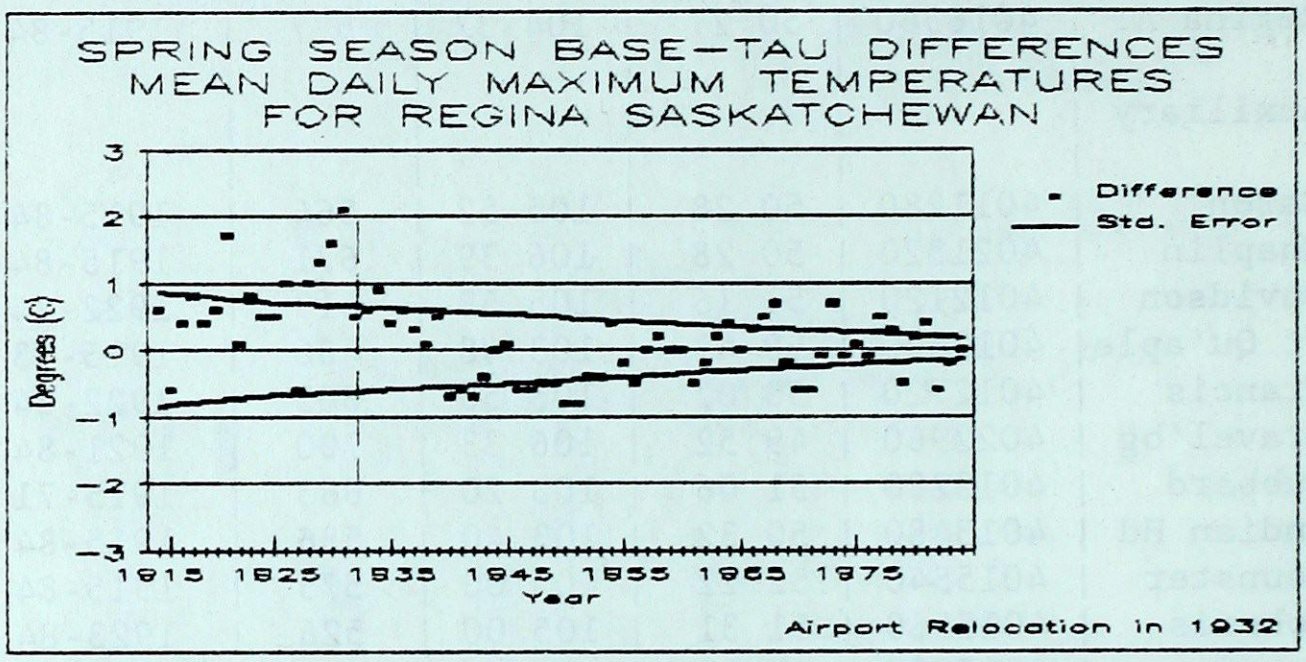
TABLE (13)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Regina Saskatchewan

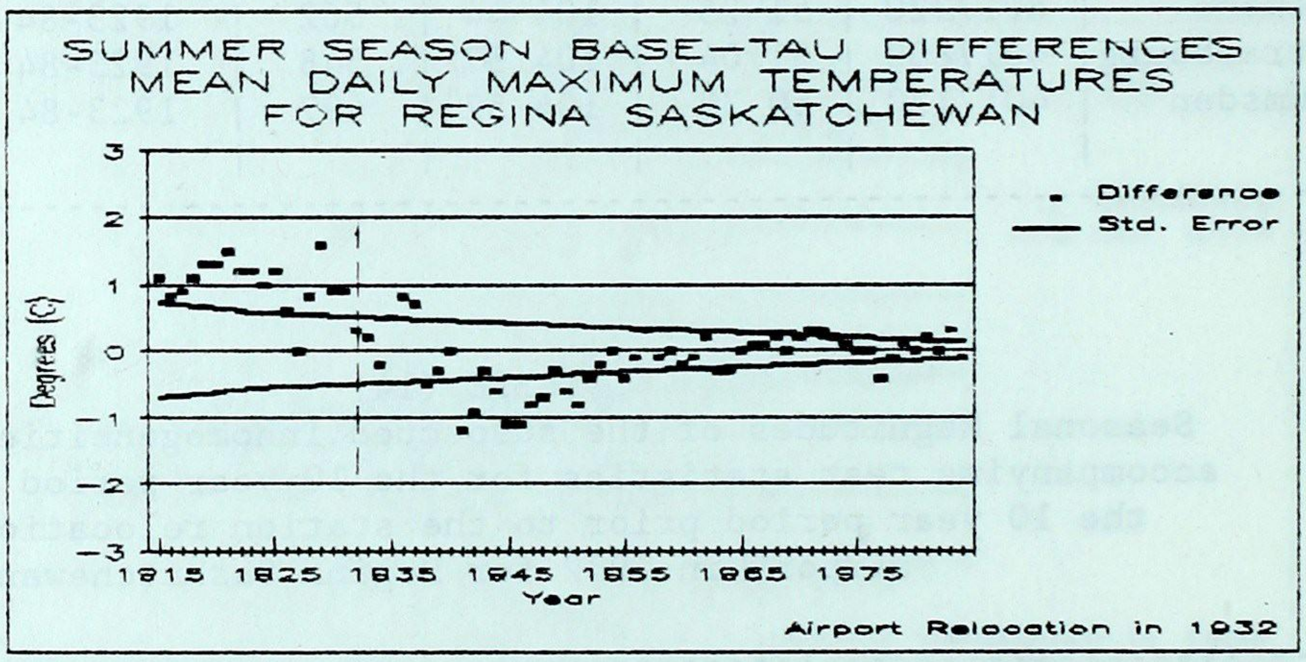
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Regina A.	4016560	50 27	104 37	577	1915-84	Airport(1932)
Auxiliary						
Caron	4011280	50 28	105 52	564	1915-84	3
Chaplin	4021520	50 28	106 39	671	1915-84	5
Davidson	4012120	51 16	105 59	619	1922-84	3
Ft Qu'aple	4012600	50 47	103 48	486	1915-73	1
Francis	4012720	50 07	103 50	603	1922-84	3
Gravel'bg	4022960	49 52	106 33	700	1921-84	1
Hubbard	4013280	51 06	103 20	663	1915-71	3
Indian Hd	4013480	50 32	103 40	586	1915-84	1
Meunster	4015540	52 12	105 00	575	1915-84	0
Nokomis	4015560	51 31	105 00	526	1923-84	2
Semans	4017320	51 25	104 44	562	1923-84	2
Strasbourg	4017800	51 04	104 57	548	1923-84	2
Lumsden	4017120	50 39	104 52	497	1923-84	3

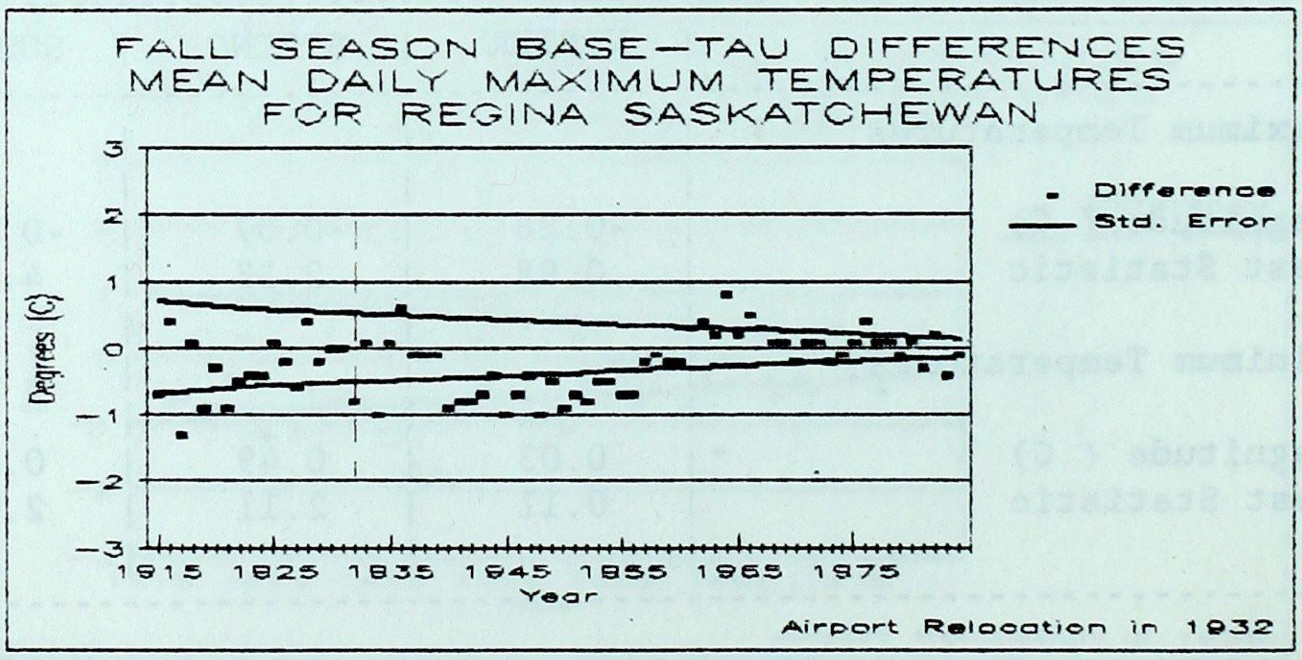
TABLE (14)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1932 for Regina Saskatchewan

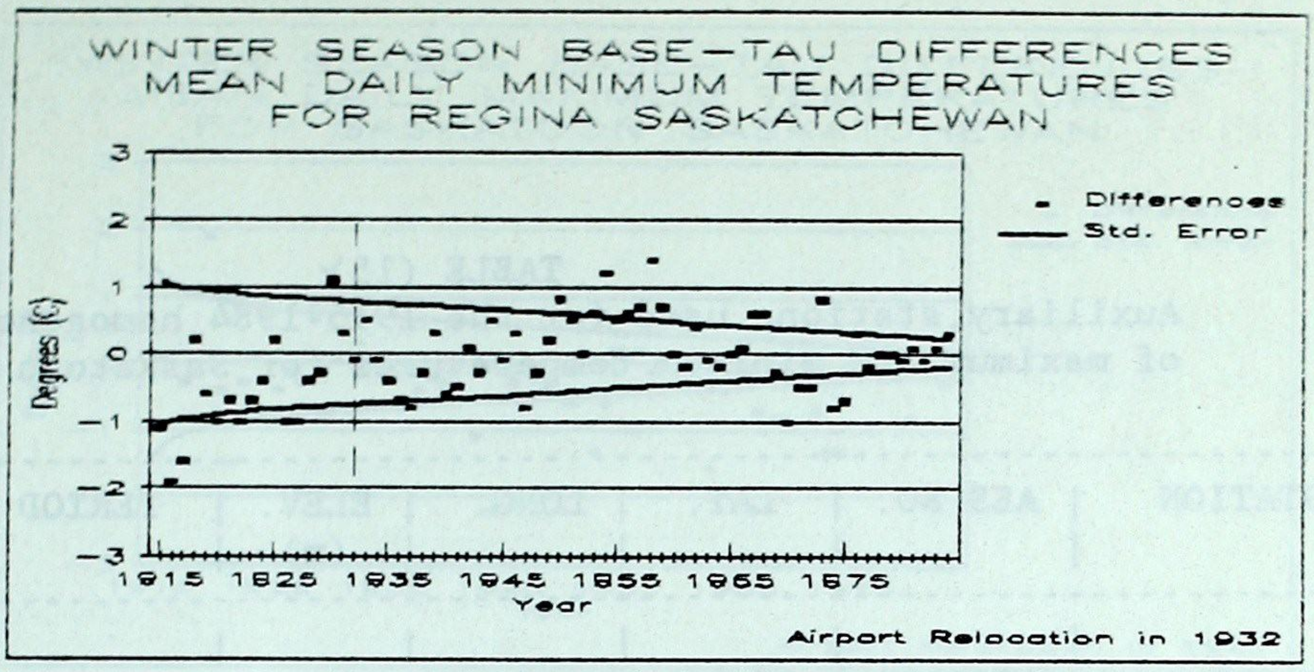
	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-0.26	-0.57	-0.91	-0.14
Test Statistic	0.98	2.33	4.68	0.68
Minimum Temperatures:				
Magnitude (C)	0.03	0.49	0.47	0.42
Test Statistic	0.11	2.11	2.71	2.21


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932


FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932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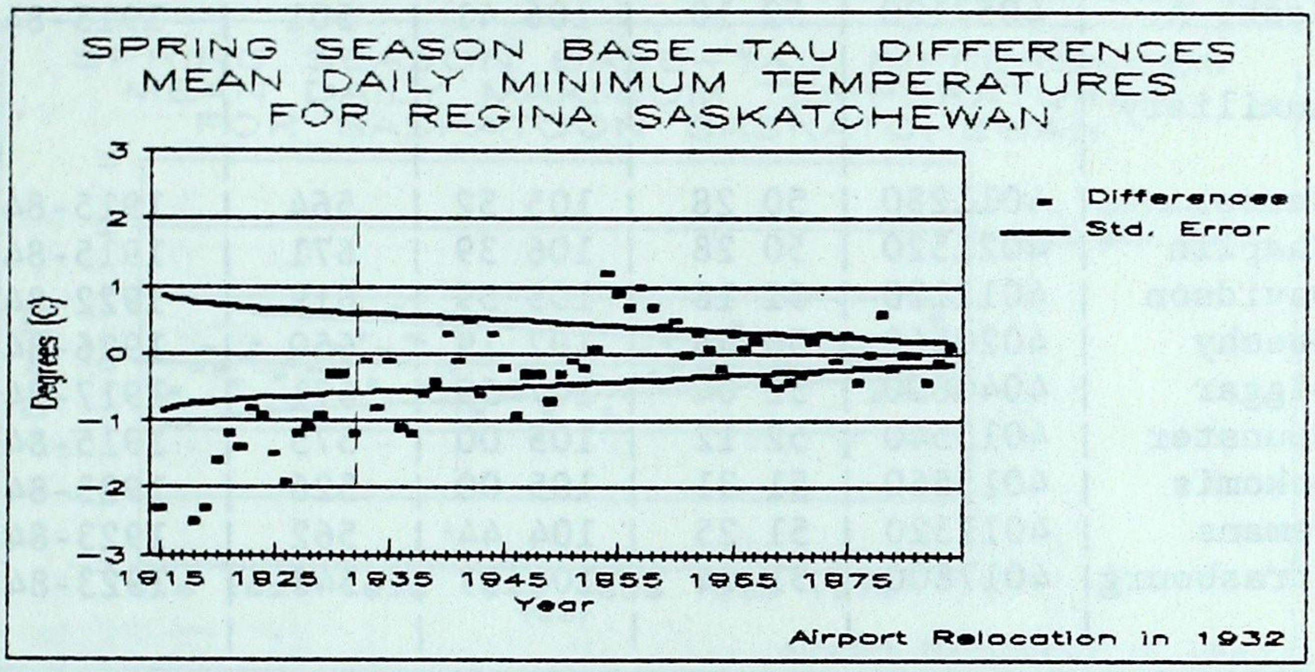
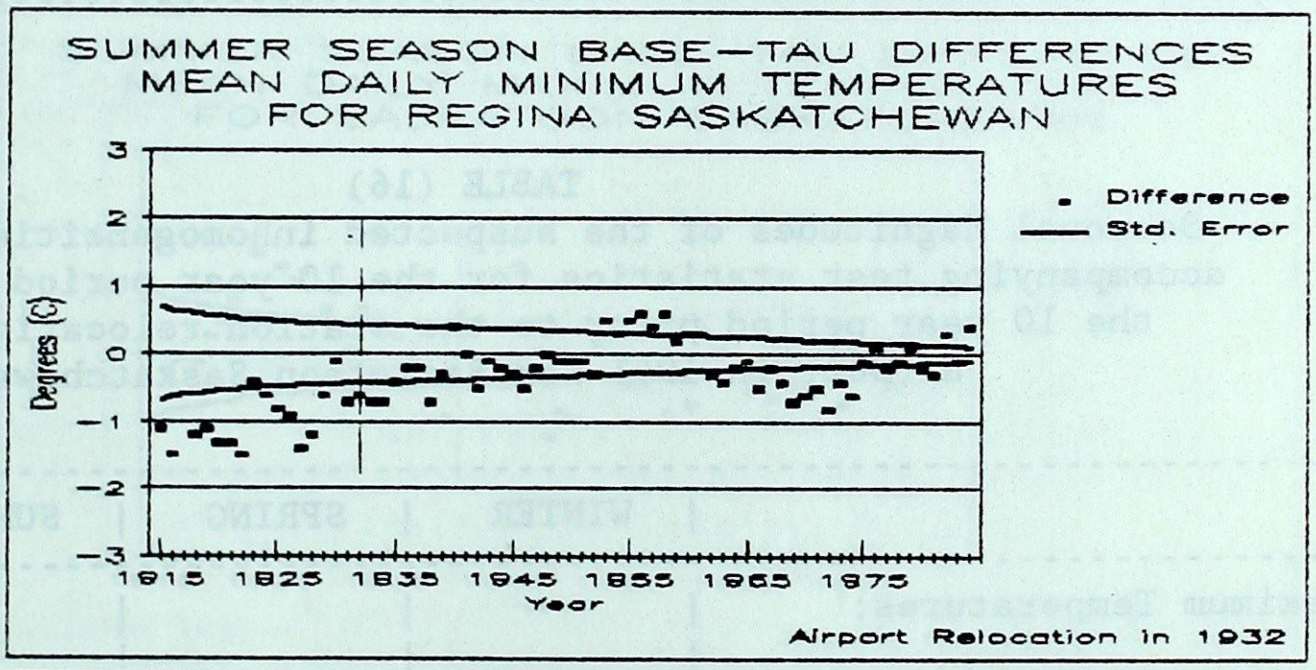
MEAN DAILY MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Differences
Std. Error
Degrees (C)
Year
Airport Relocation in 1932


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Differences
Std. Error
Degrees (C)
Year
Airport Relocation in 1932


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932

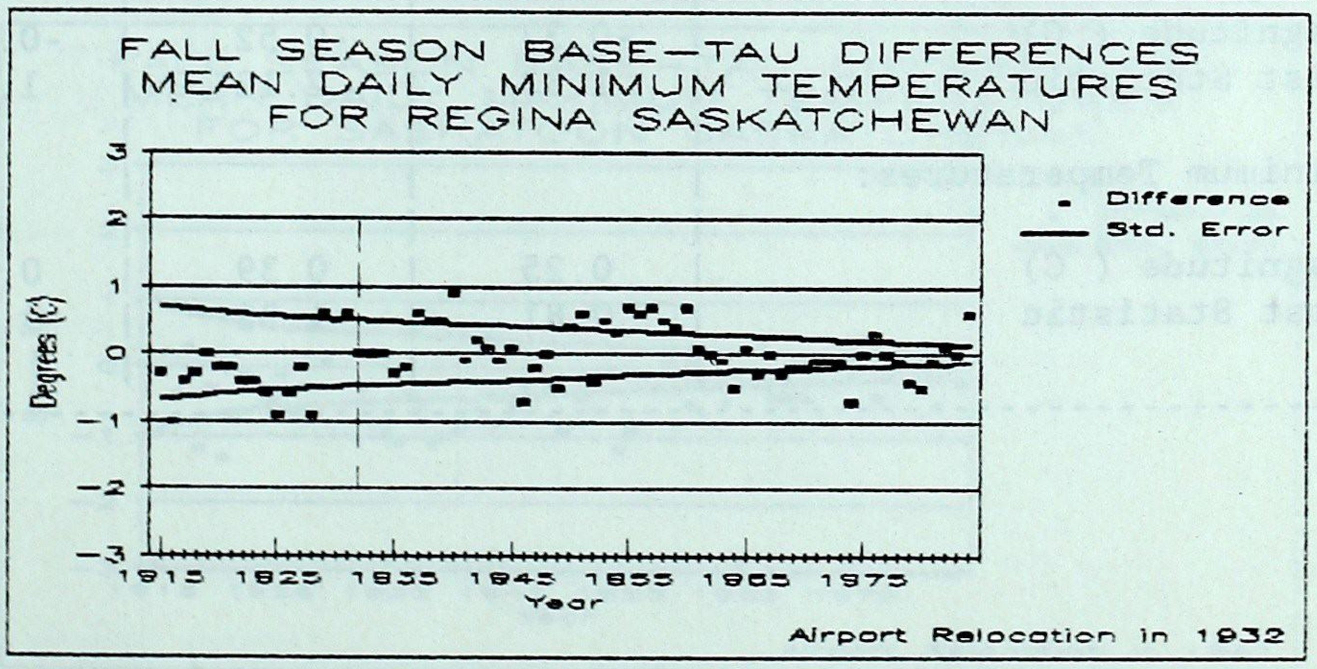
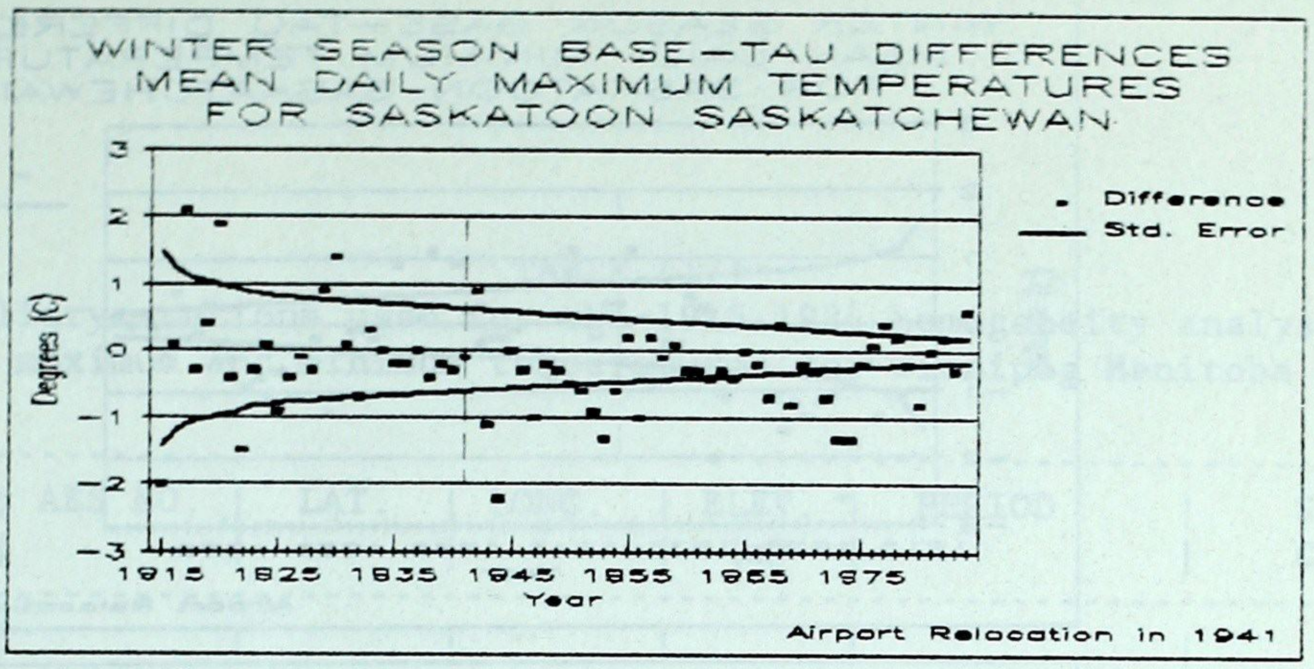

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR REGINA SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1932

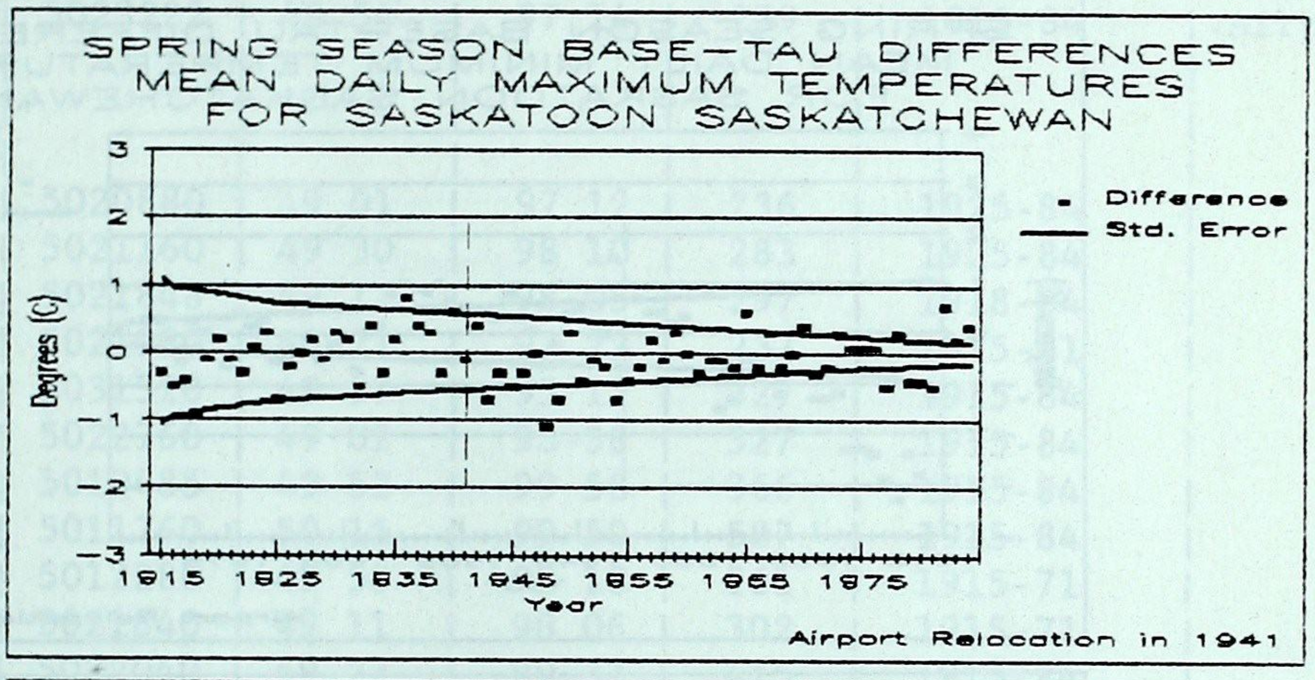
TABLE (15)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Saskatoon Saskatchewan

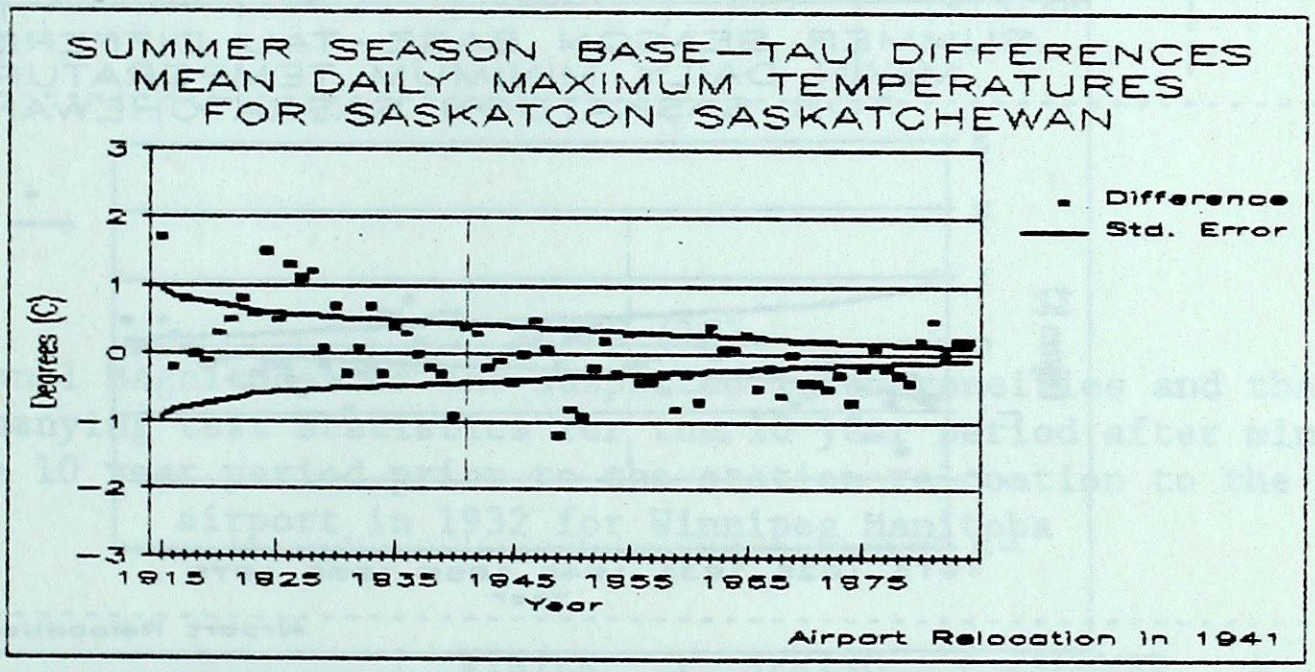
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Sask. A.	4057120	52 10	106 41	501	1915-84	Airport(1941)
Auxiliary						
Caron	4011280	50 28	105 52	564	1915-84	3
Chaplin	4021520	50 28	106 39	671	1915-84	5
Davidson	4012120	51 16	105 59	619	1922-84	3
Beechy	4020560	50 46	107 19	650	1926-84	5
Biggar	4040600	52 04	107 59	671	1917-84	4
Meunster	4015540	52 12	105 00	575	1915-84	0
Nokomis	4015560	51 31	105 00	526	1923-84	2
Semans	4017320	51 25	104 44	562	1923-84	2
Strasbourg	4017800	51 04	104 57	548	1923-84	2

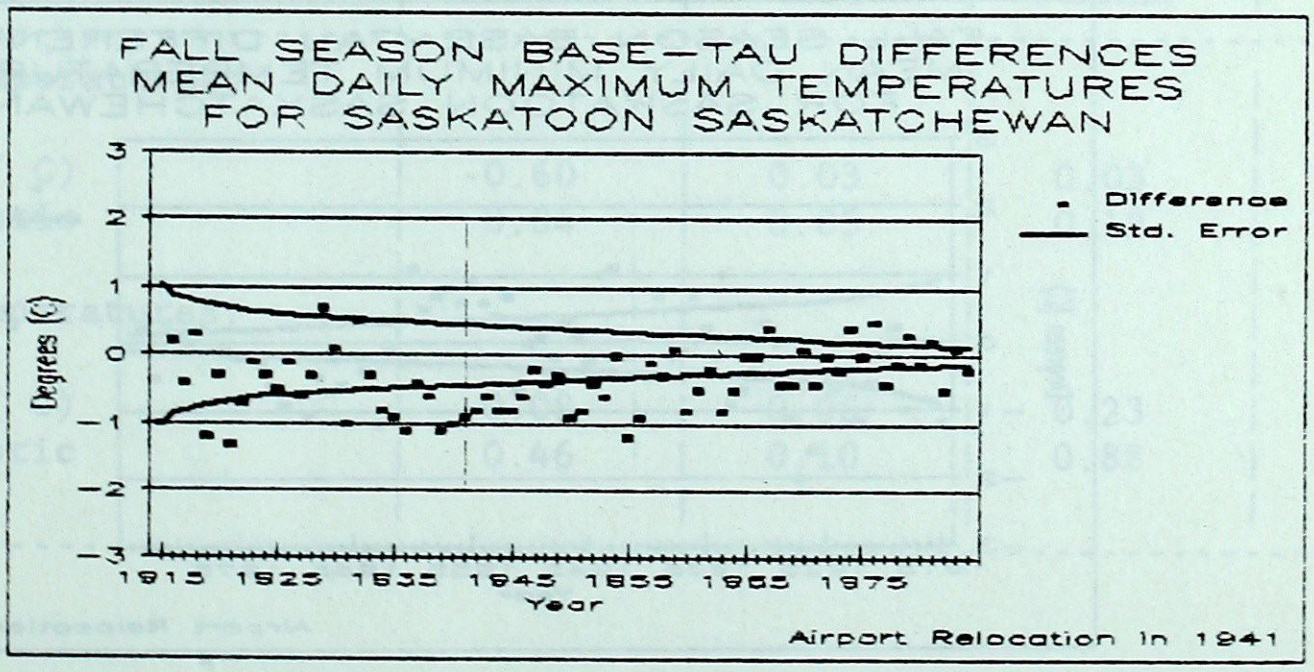
TABLE (16)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1941 for Saskatoon Saskatchewan

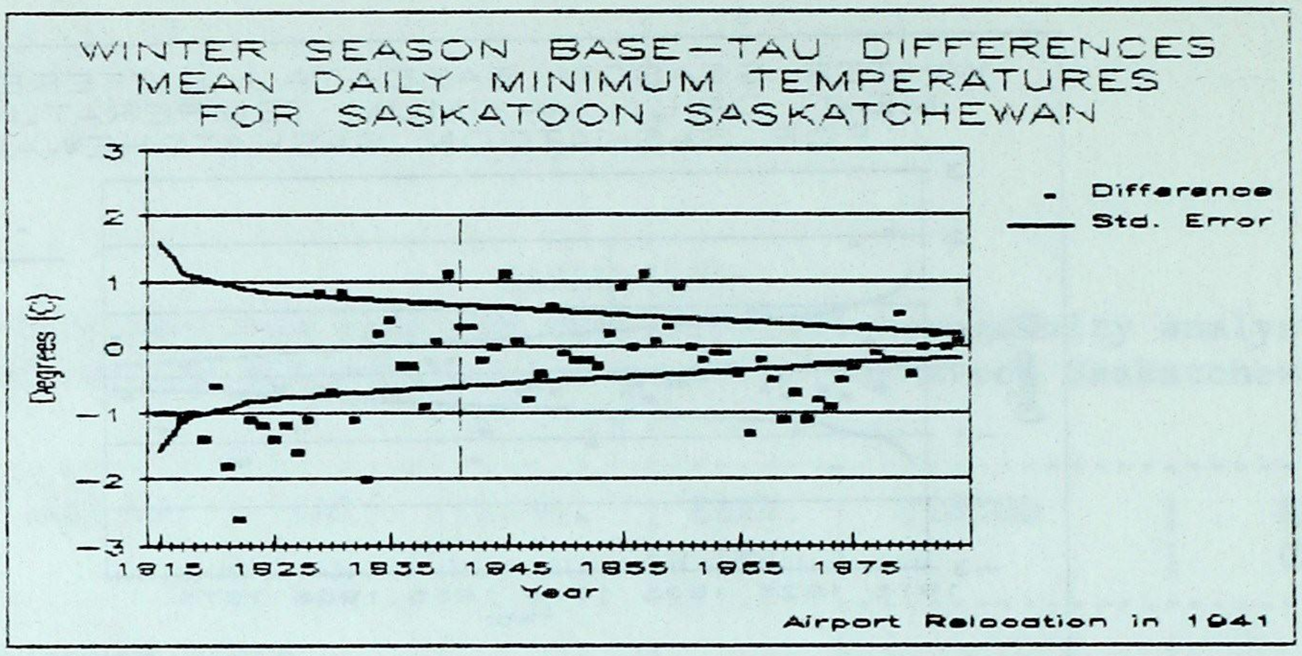
	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-0.37	-0.52	-0.22	0.02
Test Statistic	1.33	2.12	1.17	0.08
Minimum Temperatures:				
Magnitude (C)	0.25	0.39	0.64	0.27
Test Statistic	0.81	1.32	3.56	1.44

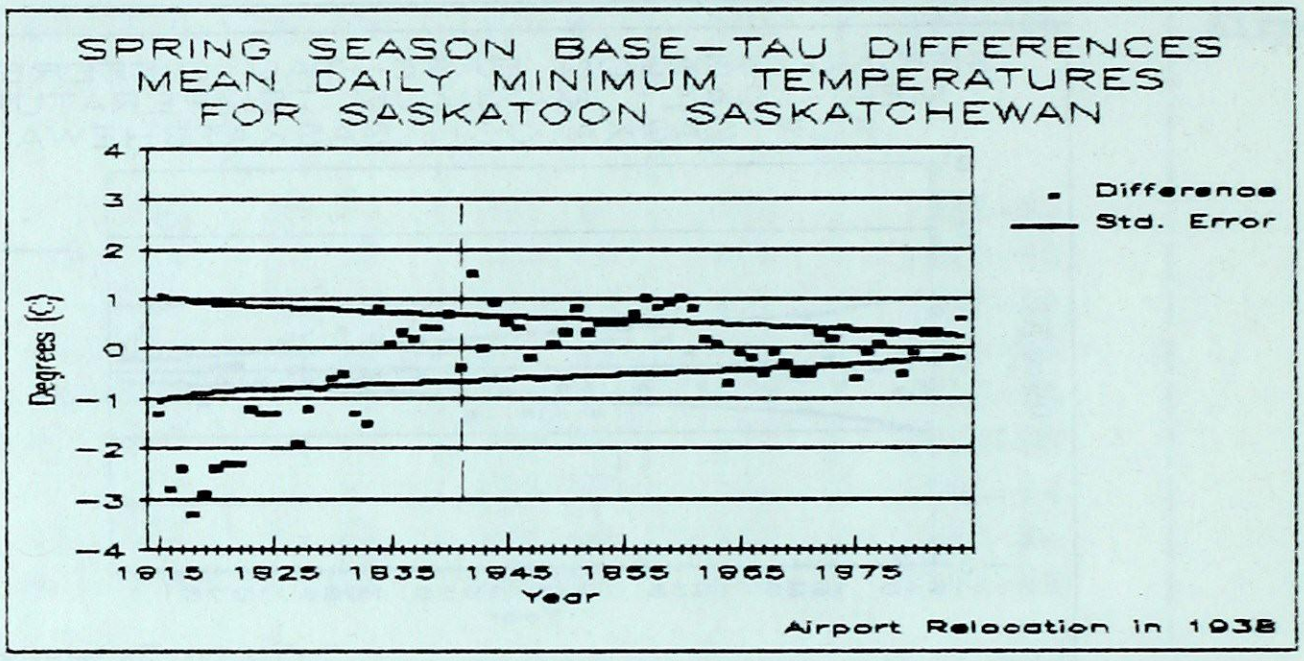

WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941

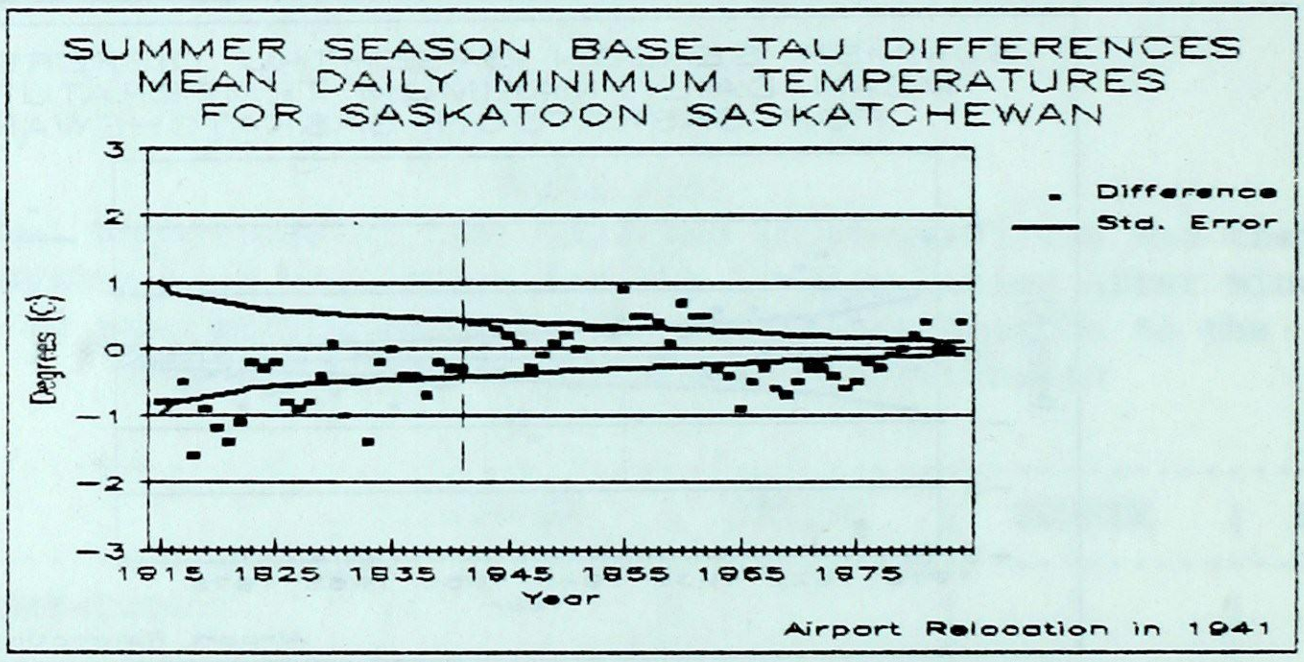

SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941


FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1938


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941

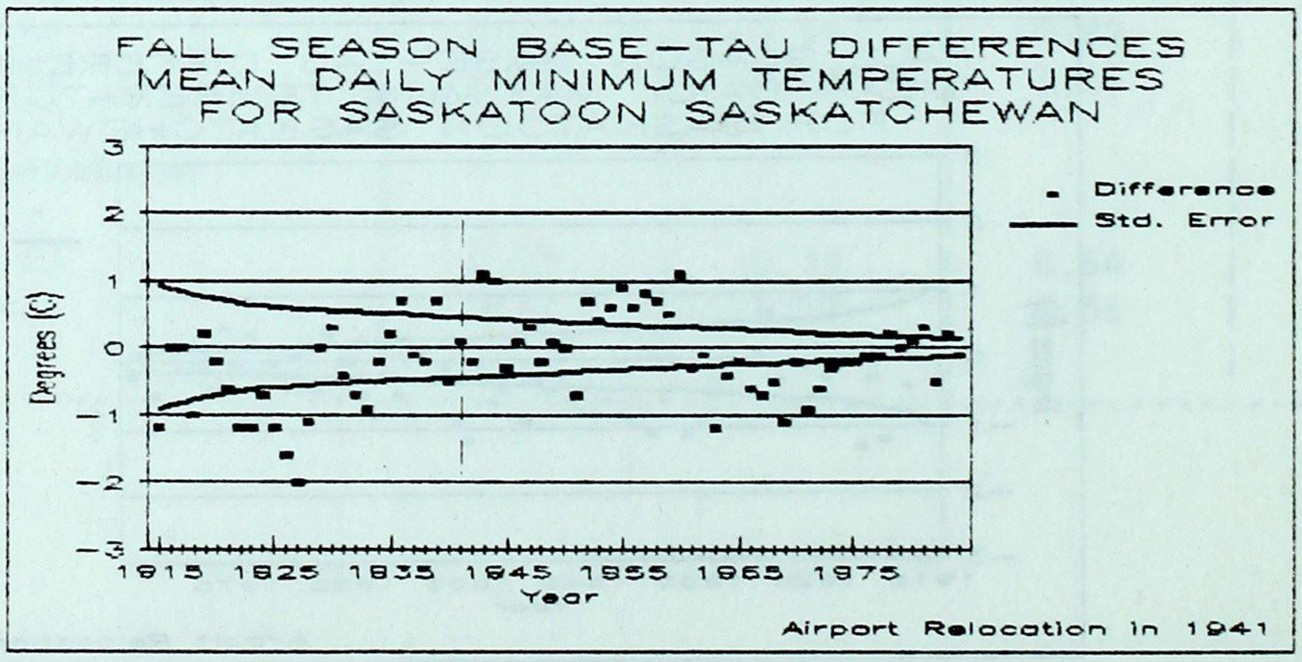

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR SASKATOON SASKATCHEWAN
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1941

TABLE (17)

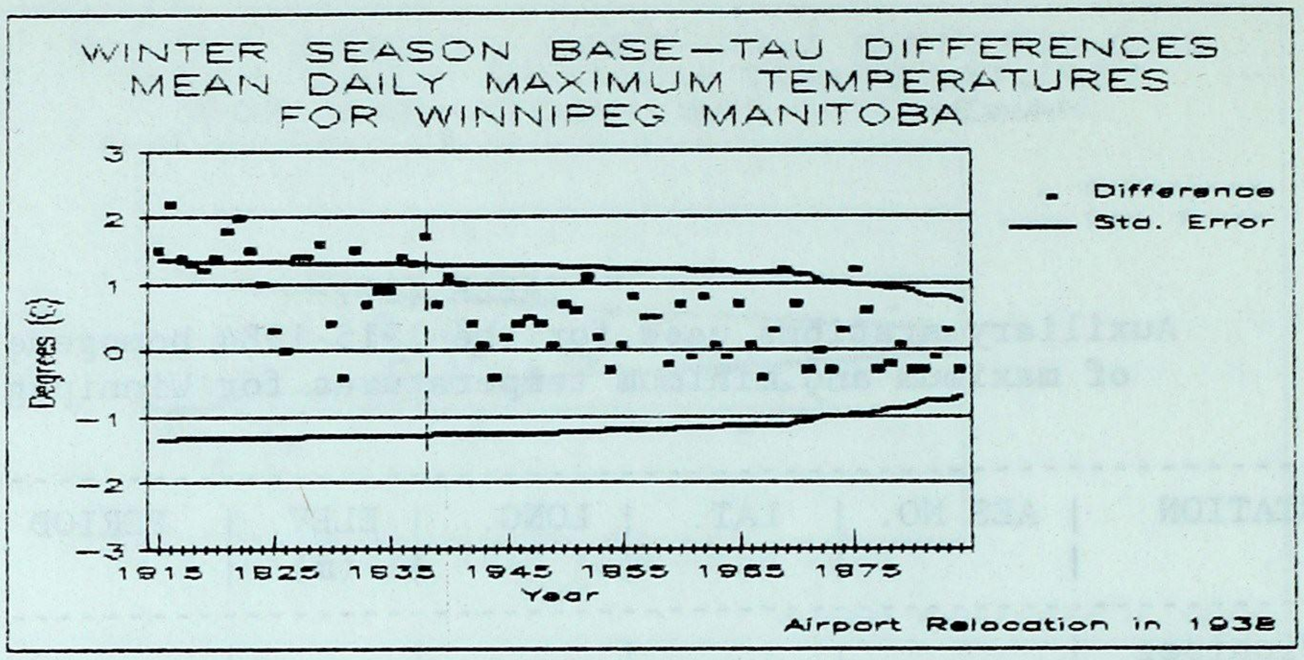
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Winnipeg Manitoba

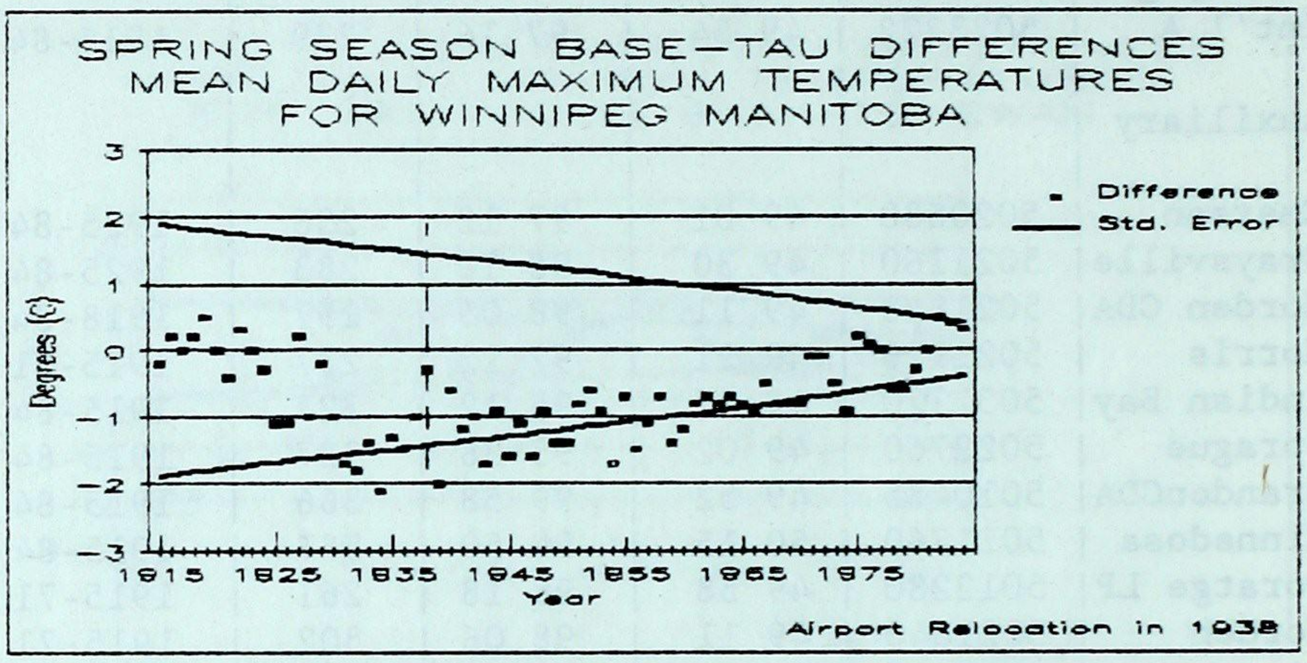
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Winnipeg Int'l A.	5023222	49 54	97 14	239	1915-84	Airport(1938)
Auxiliary						
Emerson	5020880	49 01	97 12	236	1925-84	5
Graysville	5021160	49 30	98 10	283	1925-84	2
Morden CDA	5021848	49 11	98 05	297	1918-84	1
Morris	5021920	49 21	97 22	237	1915-81	3
Indian Bay	5031320	49 37	95 12	327	1915-84	0
Sprague	5022760	49 02	95 38	327	1915-84	3
BrandonCDA	5010485	49 52	99 58	366	1915-84	2
Minnedosa	5011760	50 15	99 50	587	1915-84	6
Poratge LP	5012280	49 58	98 18	261	1915-71	2
Morden	5021840	49 11	98 06	302	1915-71	0
Ninette	5022040	49 23	99 37	415	1915-84	5

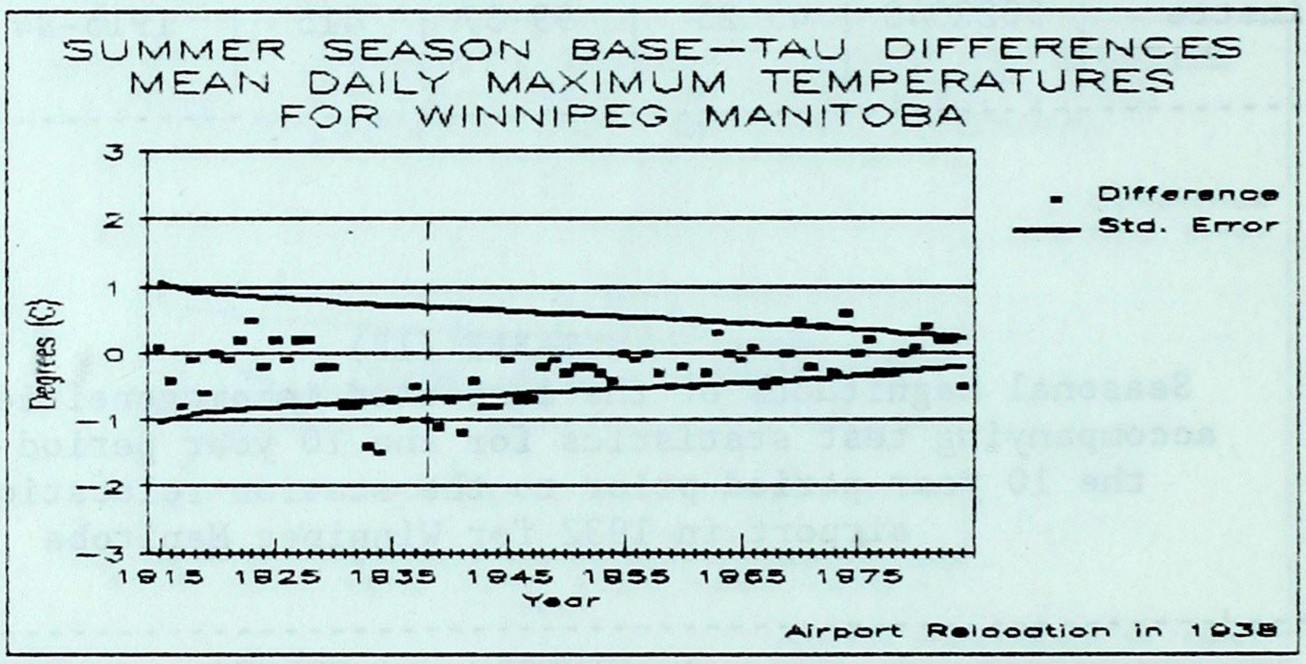
TABLE (18)

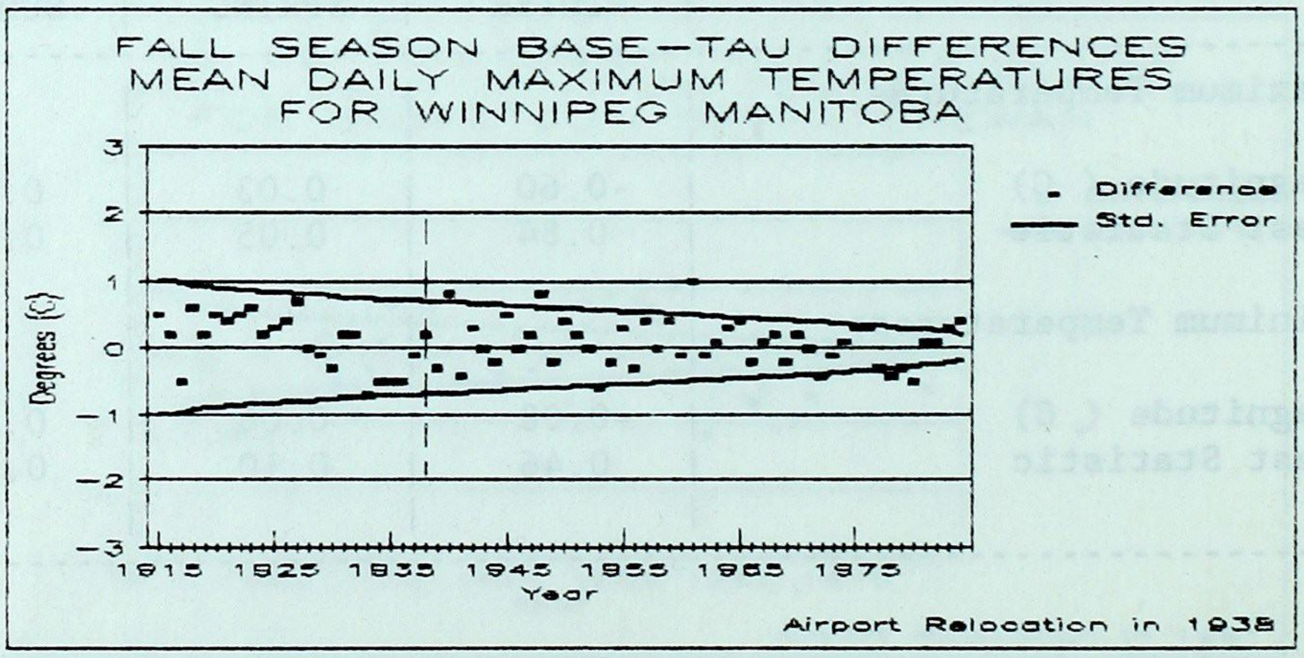
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1932 for Winnipeg Manitoba

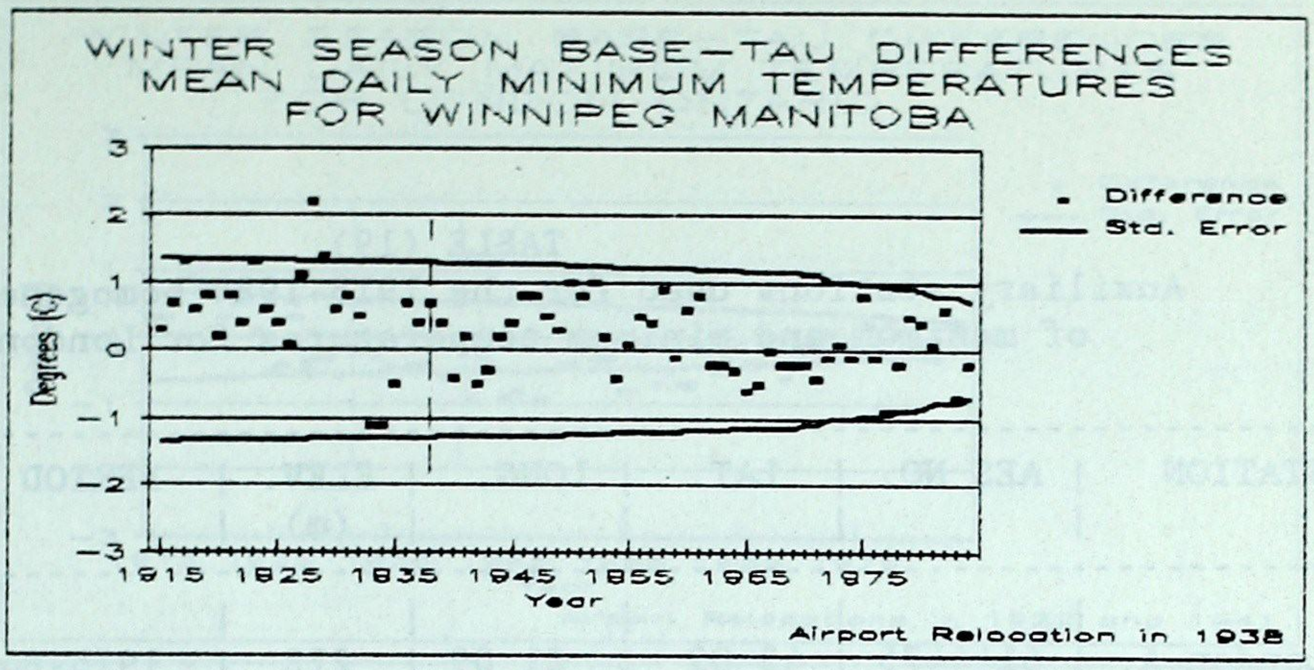
	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-0.60	0.03	0.03	0.39
Test Statistic	0.84	0.05	0.12	1.29
Minimum Temperatures:				
Magnitude (C)	-0.08	0.06	0.23	-0.12
Test Statistic	0.46	0.10	0.88	0.38

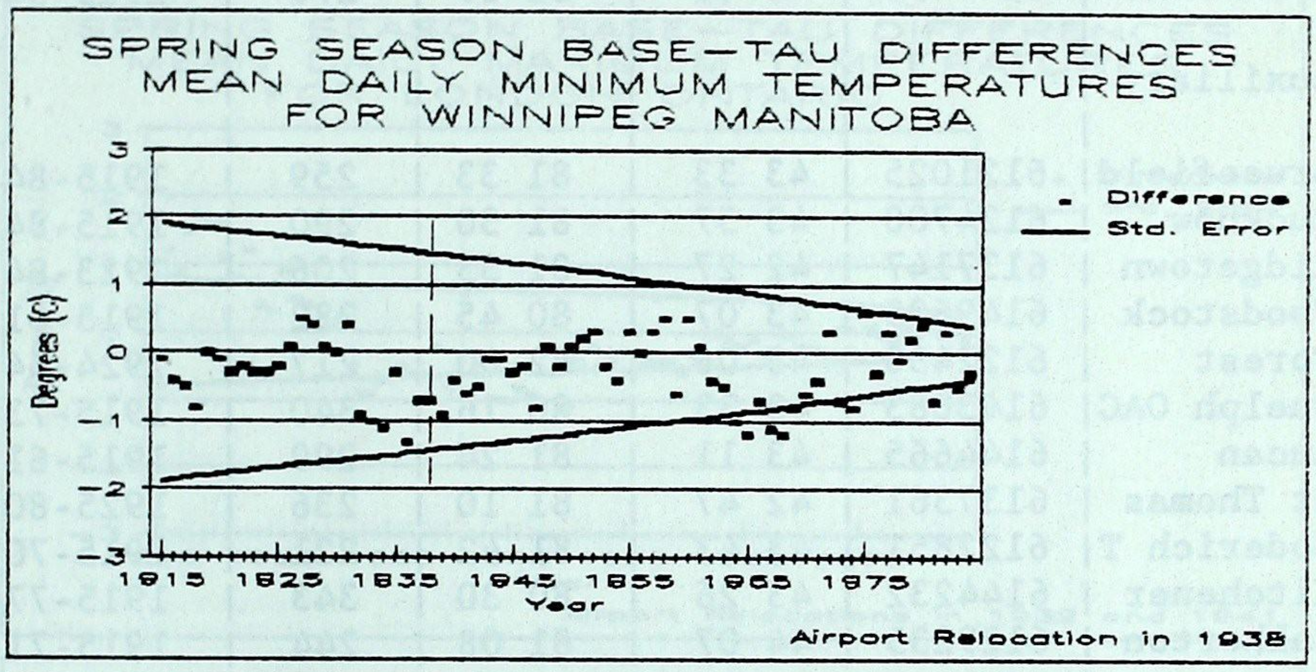

WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1938

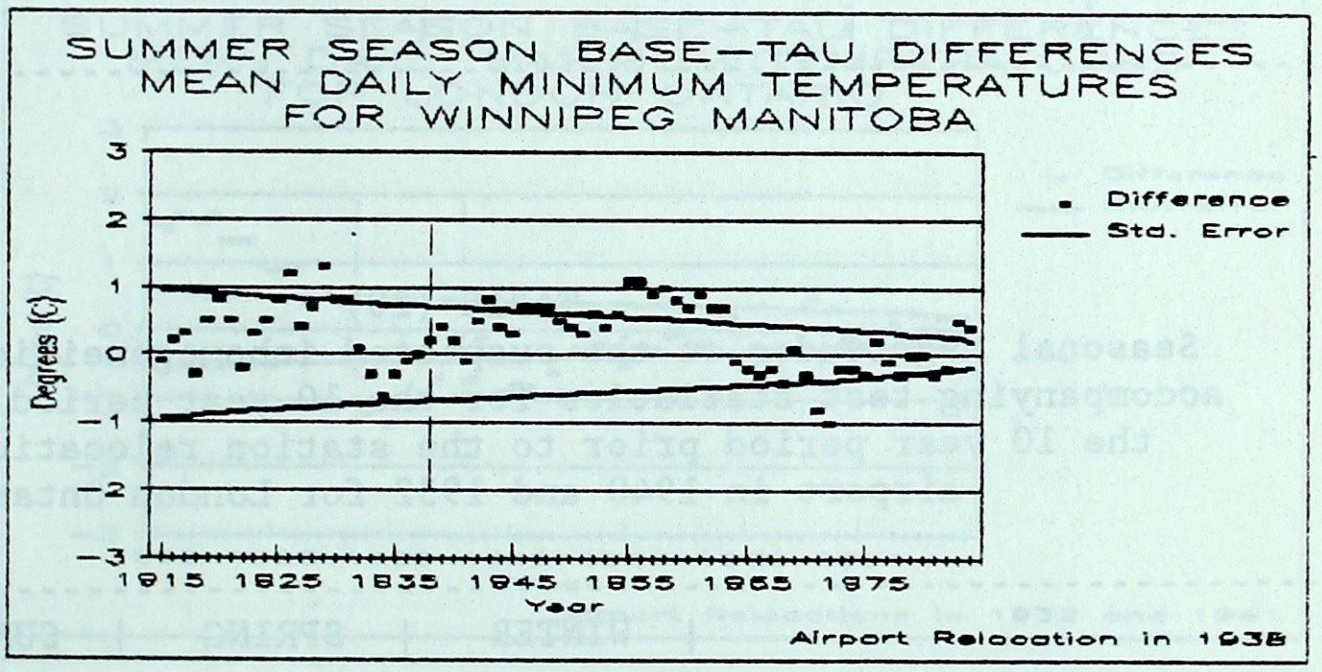

SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1938


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1938


FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1938


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938

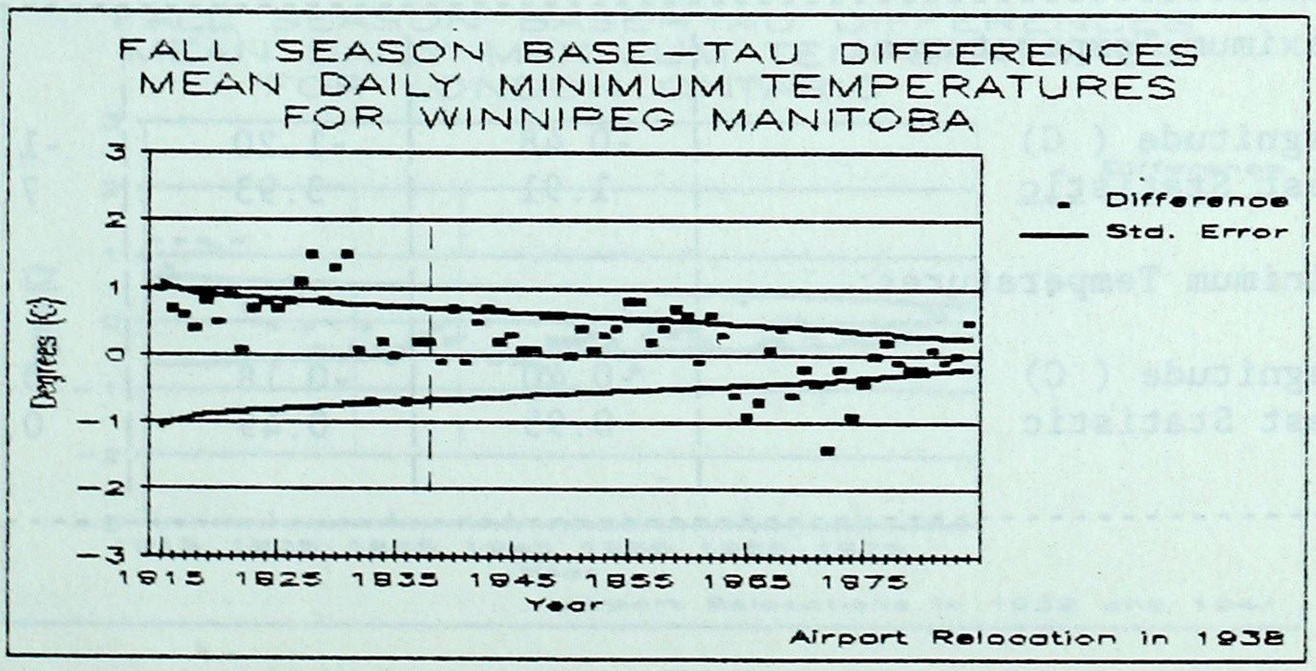
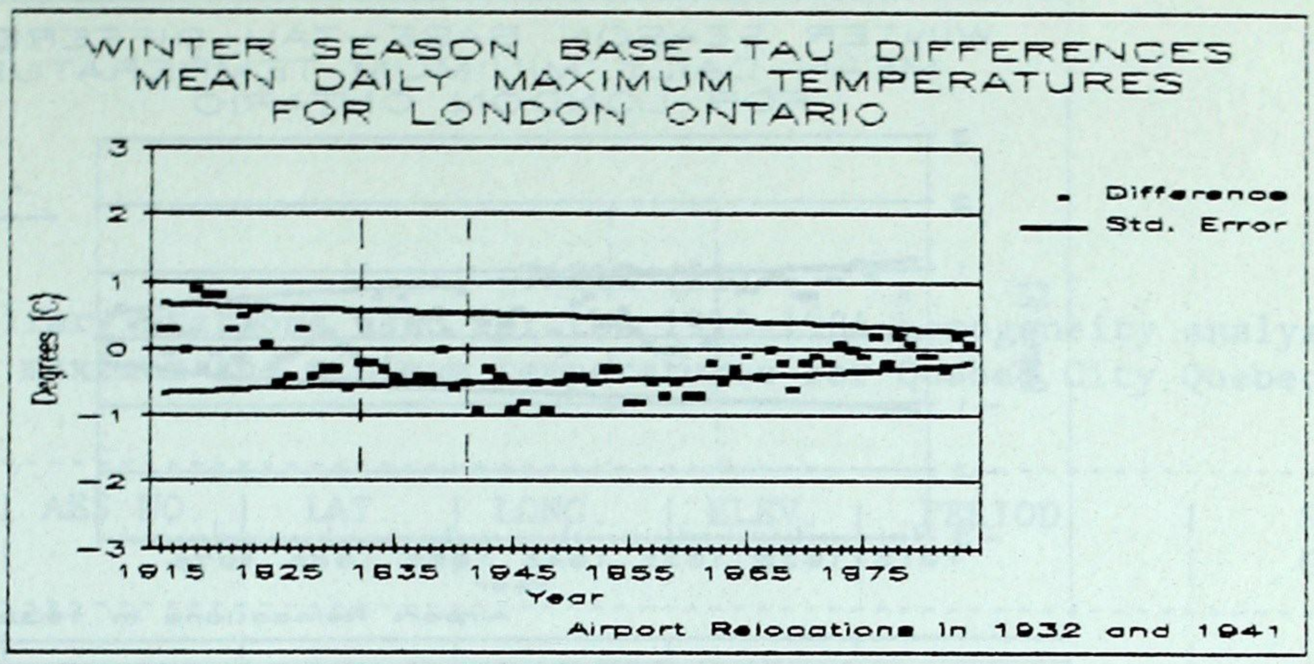

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR WINNIPEG MANITOBA
Difference
Std. Error
Degrees (C)
Year
Airport Relocation in 1938

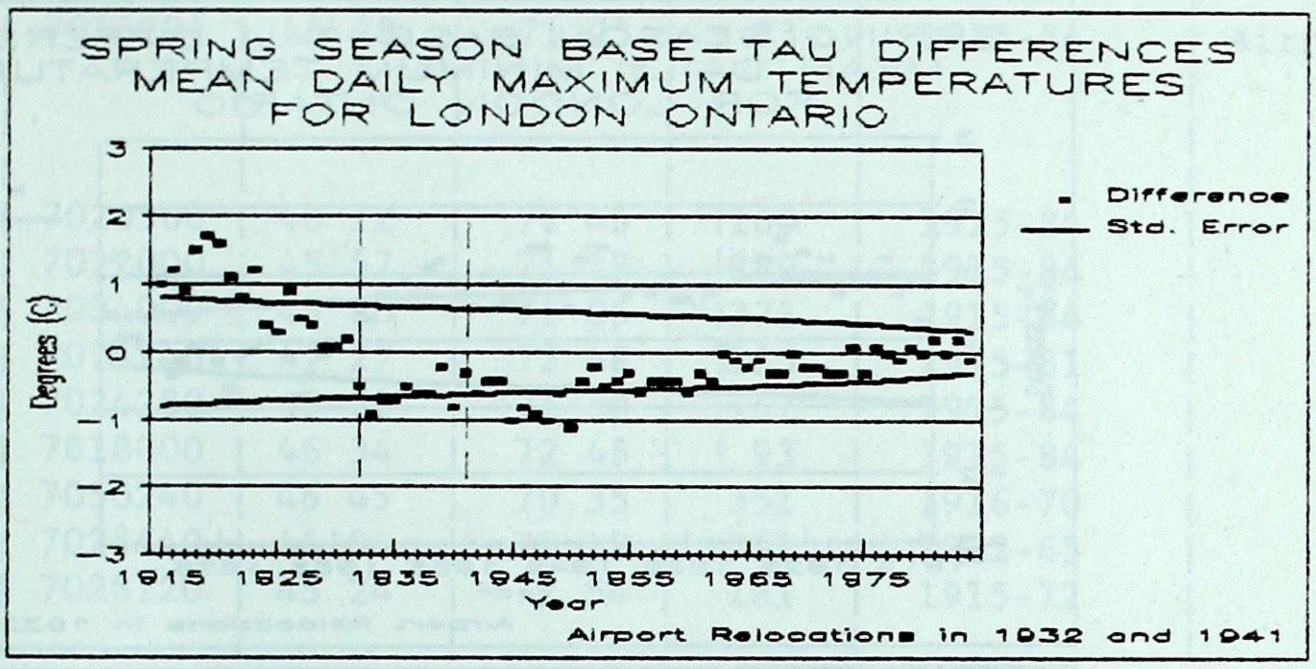
TABLE (19)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for London Ontario

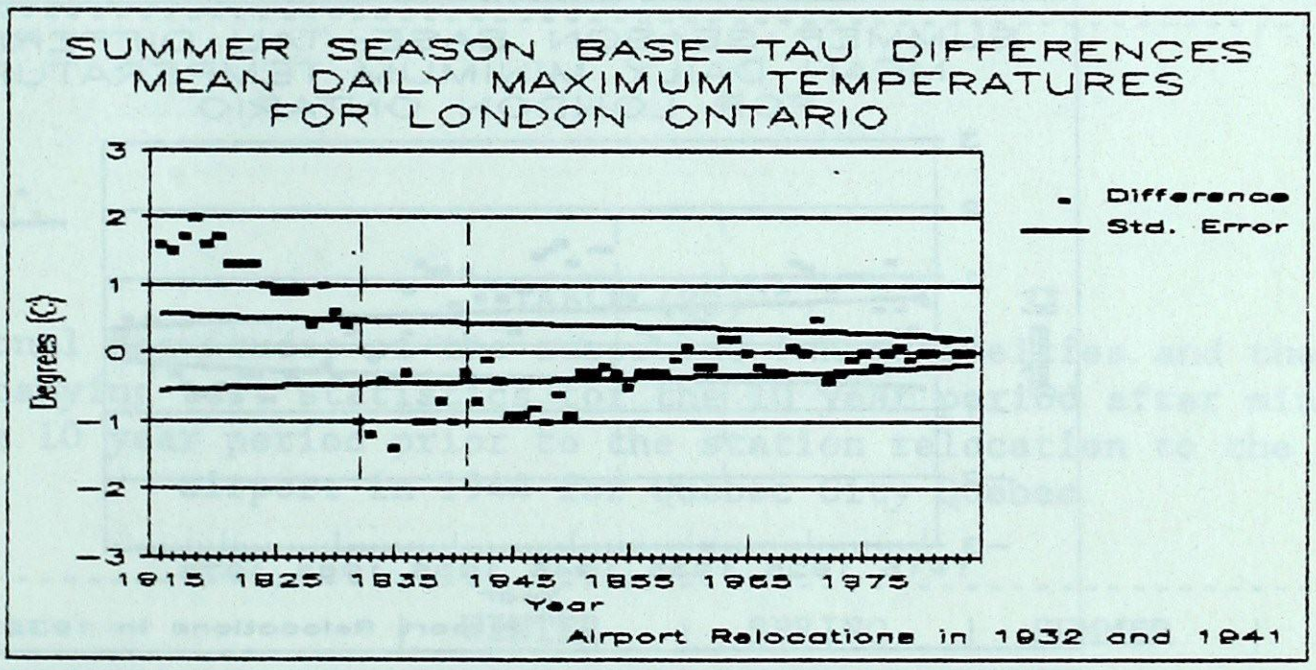
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
London A.	6144475	43 02	81 09	278	1915-84	Airport (1932 & 1940)
Auxiliary						
Brucefield	6121025	43 33	81 33	259	1915-84	0
Lucknow	6124700	43 57	81 30	290	1915-84	3
Ridgetown	6137147	42 27	81 53	206	1923-84	0
Woodstock	6149625	43 07	80 45	282	1915-81	2
Forest	6122450	43 06	82 00	217	1924-64	1
Guelph OAC	6143083	43 33	80 16	340	1915-73	0
Lucan	6144665	43 11	81 24	299	1915-61	2
St Thomas	6137361	42 47	81 10	236	1925-80	0
Goderich T	6122851	43 43	81 42	221	1915-70	1
Kitchener	6144232	43 26	80 30	343	1915-77	1
Walkerton	6129235	44 07	81 08	244	1915-71	1

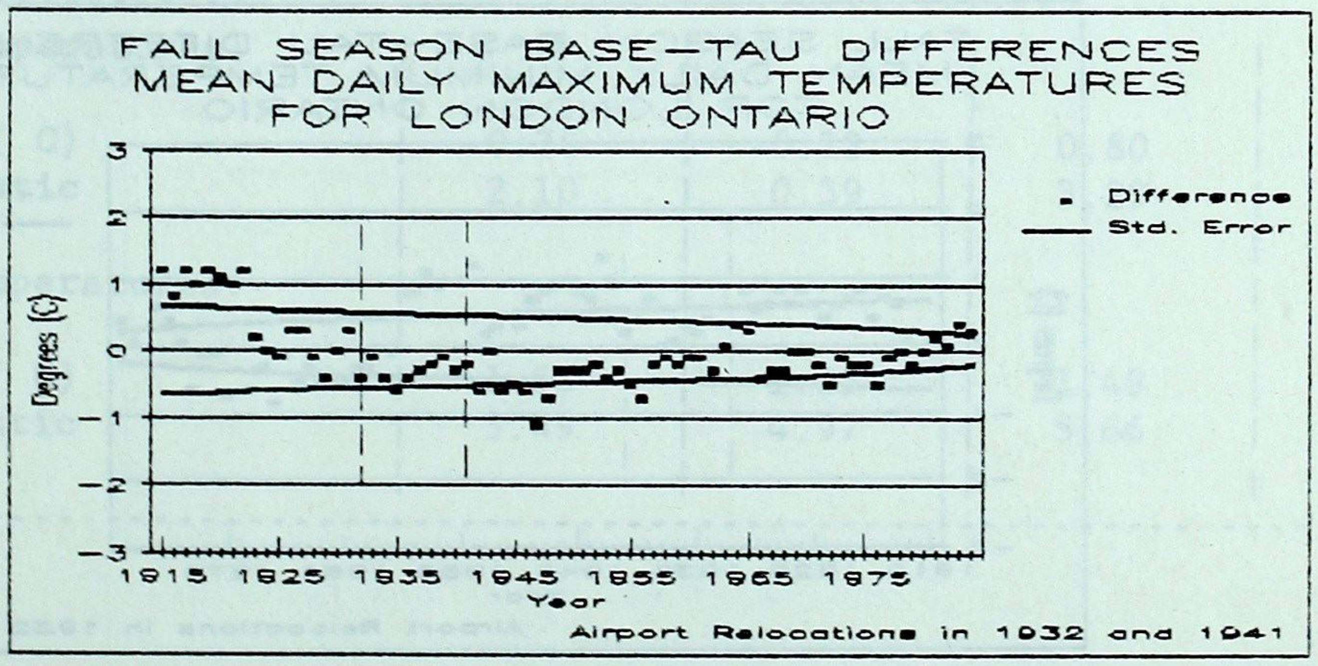
TABLE (20)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocations to the airport in 1940 and 1932 for London Ontario

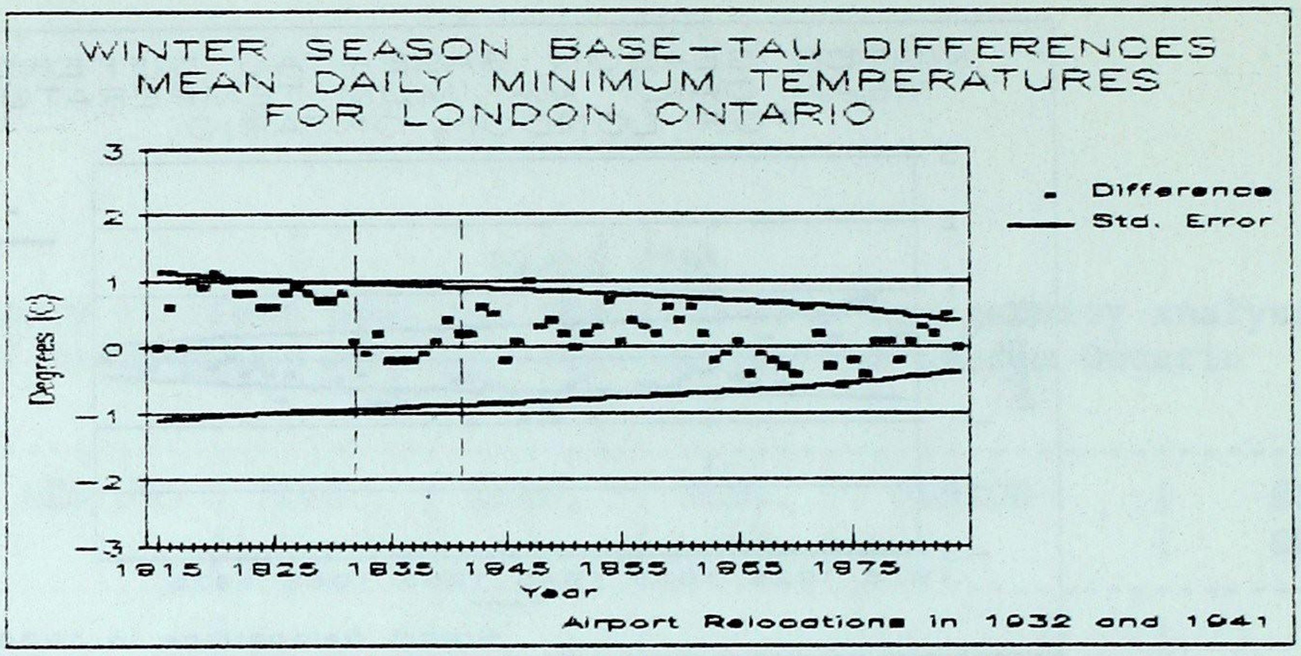
	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-0.48	-1.20	-1.54	-0.65
Test Statistic	1.91	3.93	7.41	2.76
Minimum Temperatures:				
Magnitude (C)	-0.40	-0.18	0.12	0.12
Test Statistic	0.95	0.49	0.45	0.49

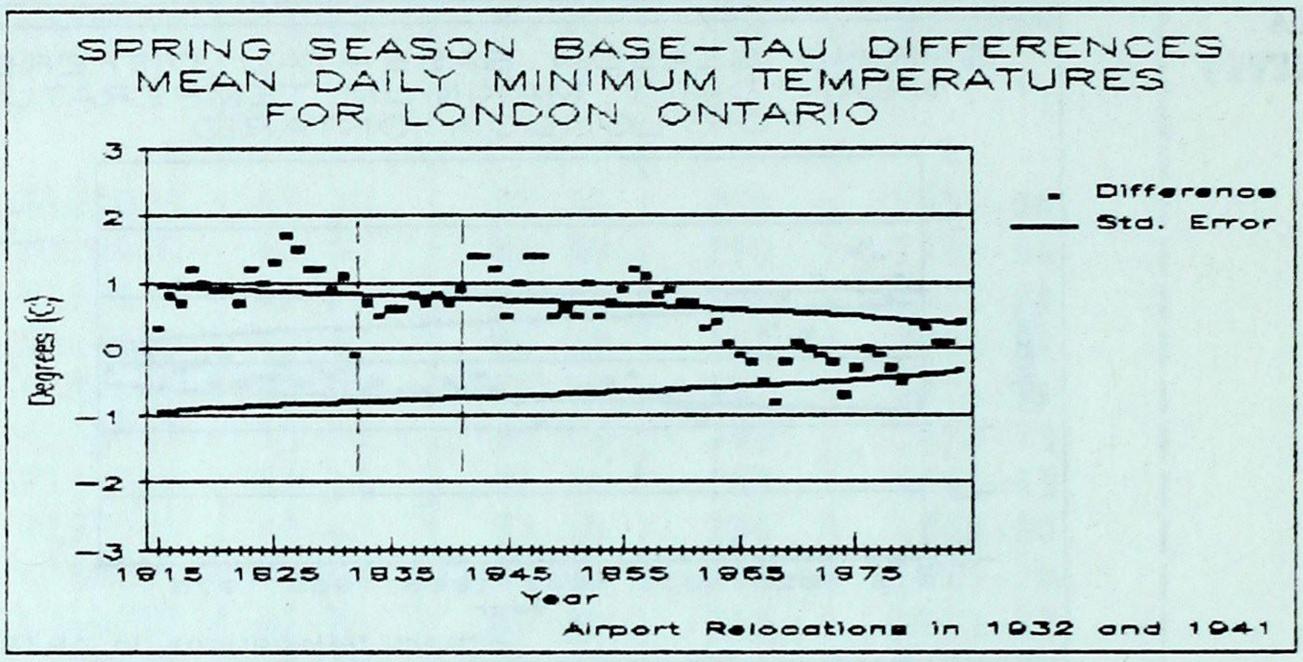

WINTER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
3
2
1
0
-1
-2
-3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocations in 1932 and 1941

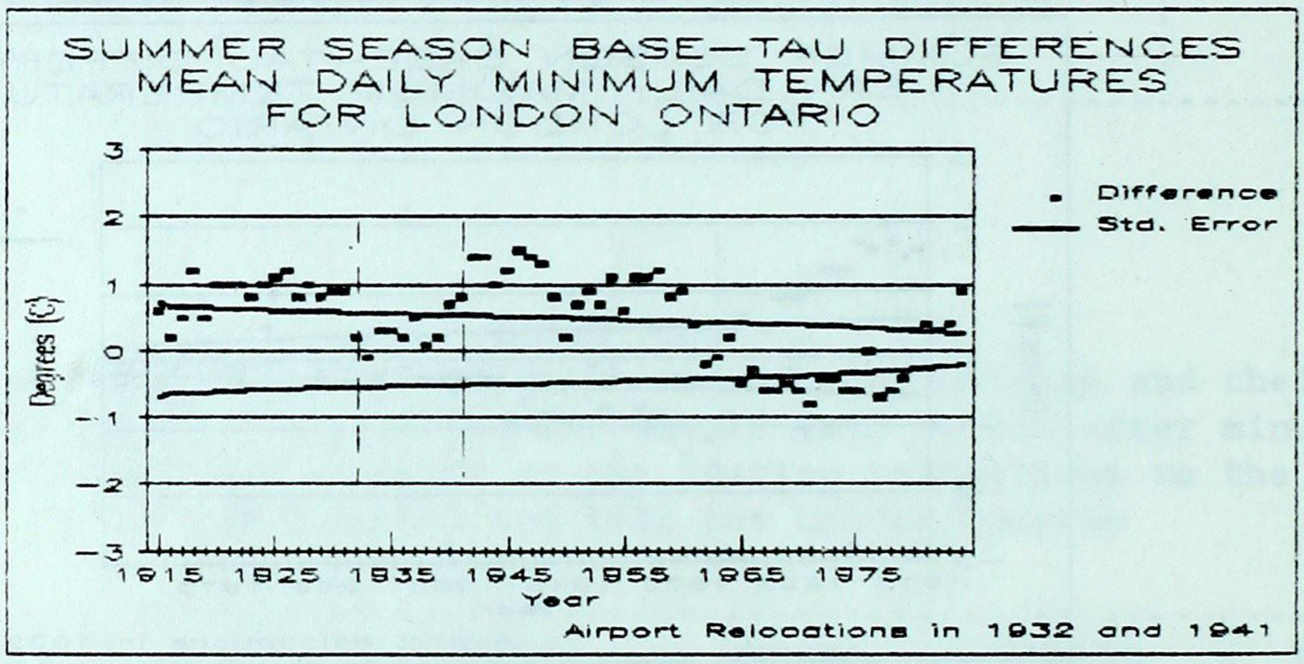

SPRING SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
3
2
1
0
-1
-2
-3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocations in 1932 and 1941


SUMMER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
3
2
1
0
-1
-2
-3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocations in 1932 and 1941


FALL SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
3
2
1
0
-1
-2
-3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocations in 1932 and 1941


WINTER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocations in 1932 and 1941


SPRING SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocations in 1932 and 1941


SUMMER SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocations in 1932 and 1941

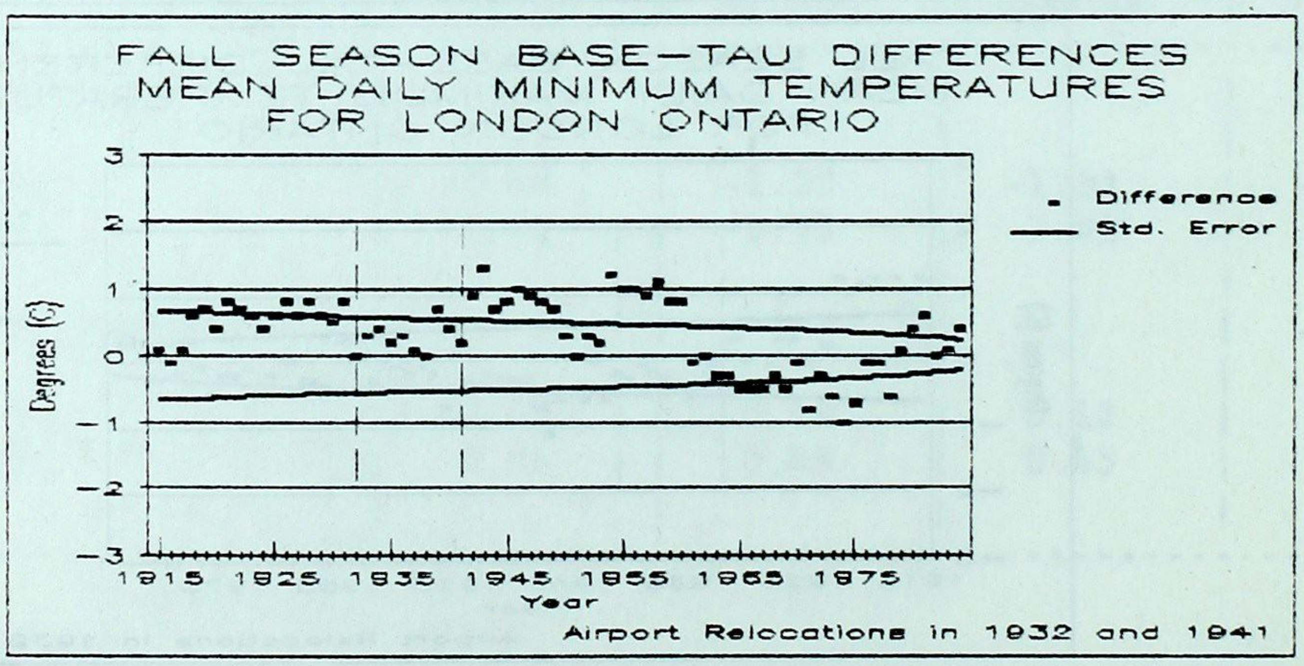
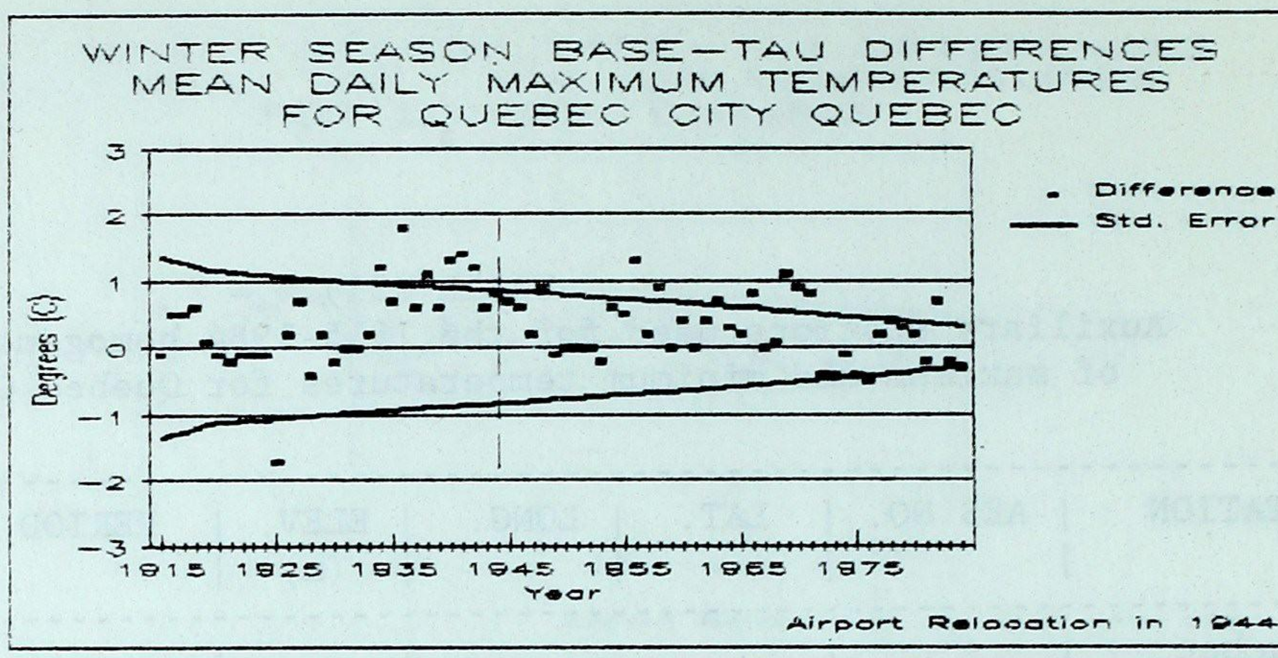

FALL SEASON BASE-TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR LONDON ONTARIO
Difference
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocations in 1932 and 1941

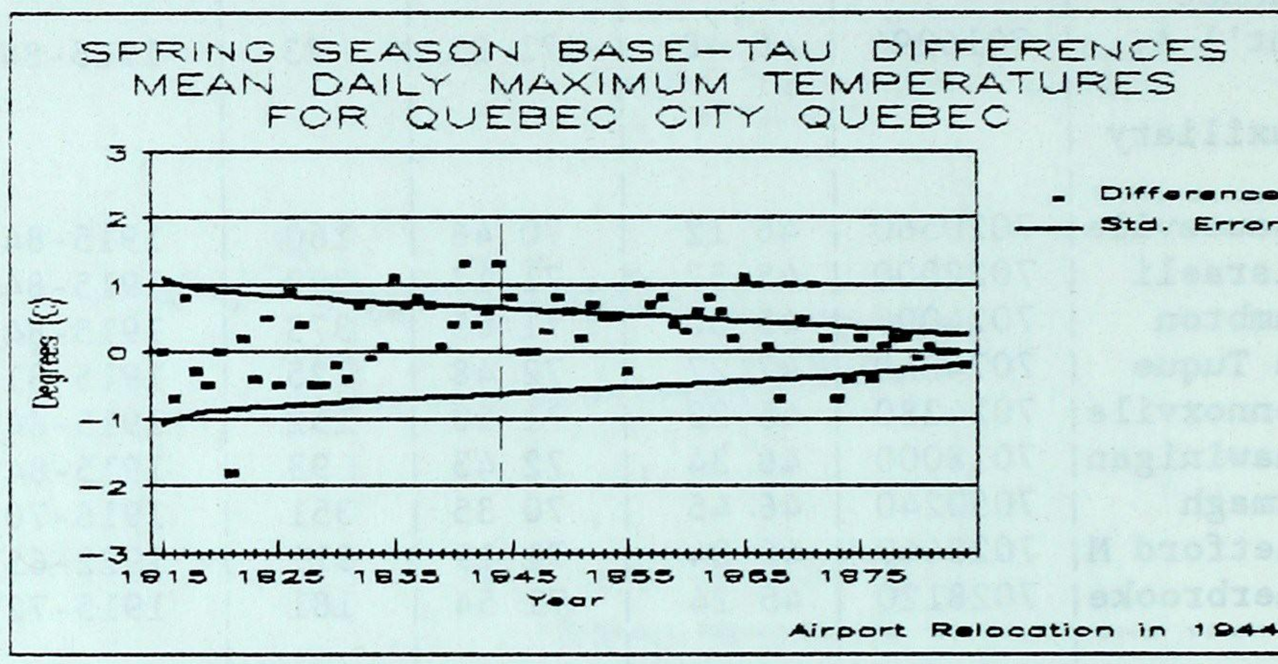
TABLE (21)
Auxiliary stations used for the 1915-1984 homogeneity analysis of maximum and minimum temperatures for Quebec City Quebec

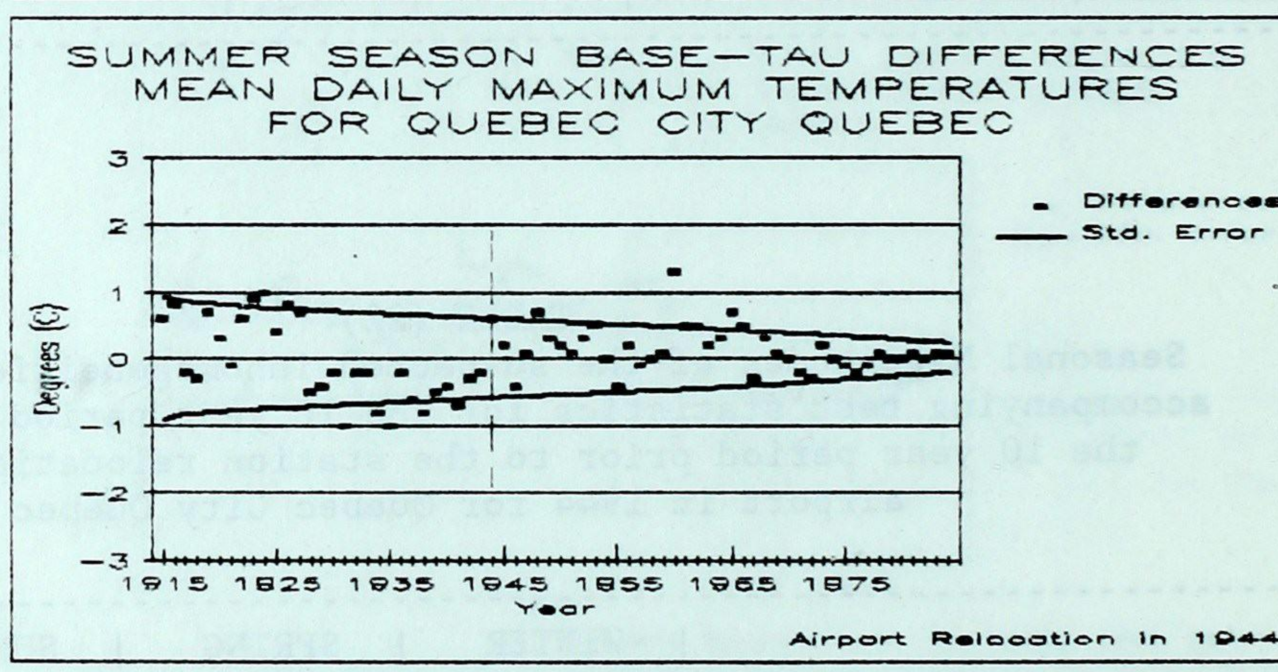
STATION	AES NO.	LAT.	LONG.	ELEV. (m)	PERIOD	STATION CHANGES
Quebec Int'l A.	7016294	46 48	71 23	73	1915-84	Airport(1944)
Auxiliary						
Beaucevile	7020560	46 12	70 46	160	1915-84	1
Disraeli	7022000	45 57	71 17	299	1915-84	1
Lambton	7024000	45 50	71 05	373	1915-84	1
La Tuque	7074240	47 27	72 48	125	1915-81	0
Lennoxvile	7024280	45 22	71 50	152	1915-84	2
Shawinigan	7018000	46 34	72 43	93	1915-84	0
Armagh	7050240	46 45	70 35	351	1916-70	0
Thetford M	7028440	46 04	71 19	311	1922-65	1
Sherbrooke	7028120	45 24	71 54	181	1915-72	3

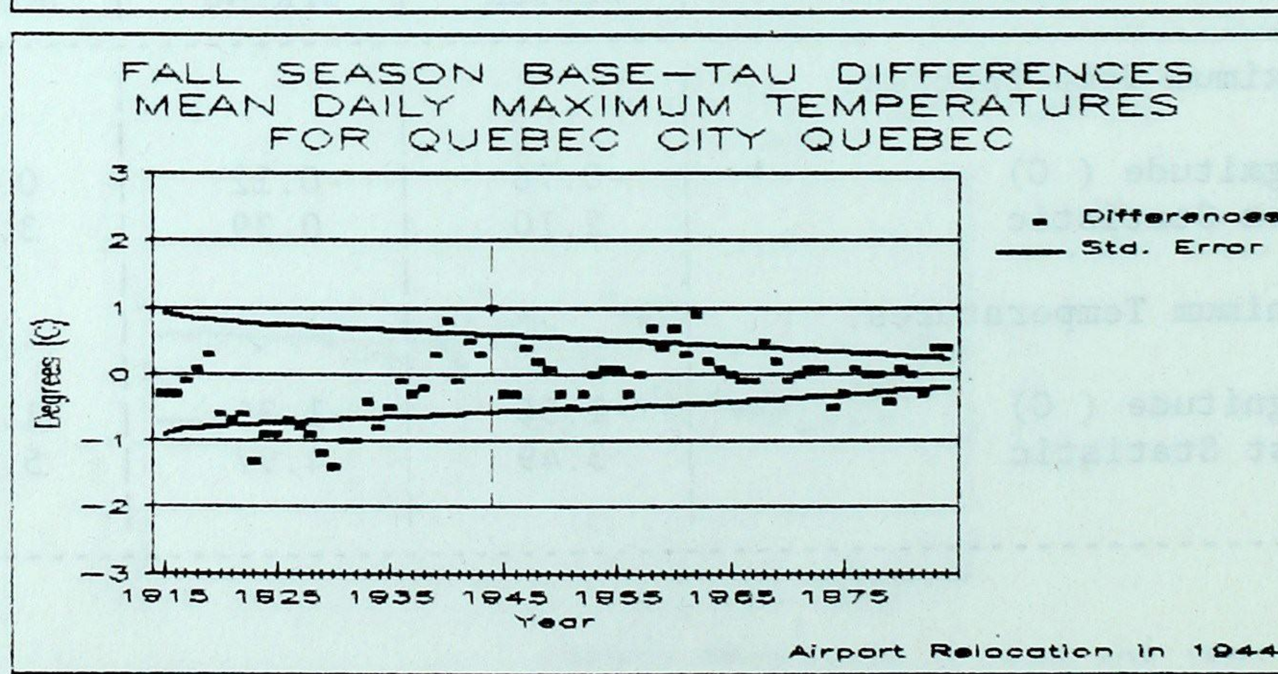
TABLE (22)
Seasonal Magnitudes of the suspected inhomogeneities and their accompanying test statistics for the 10 year period after minus the 10 year period prior to the station relocation to the airport in 1944 for Quebec City Quebec

	WINTER	SPRING	SUMMER	FALL
Maximum Temperatures:				
Magnitude (C)	-0.76	-0.12	0.80	-0.03
Test Statistic	2.10	0.39	3.29	0.11
Minimum Temperatures:				
Magnitude (C)	-1.56	-1.35	-1.49	-1.18
Test Statistic	3.49	4.97	5.66	5.16


WINTER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1944


SPRING SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Difference
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1944


SUMMER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Differences
Std. Error
Degrees (C)
3
2
1
0
−1
−2
−3
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1944


FALL SEASON BASE—TAU DIFFERENCES
MEAN DAILY MAXIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Differences
Std. Error
Degrees (C)
3
2
1
0
−1
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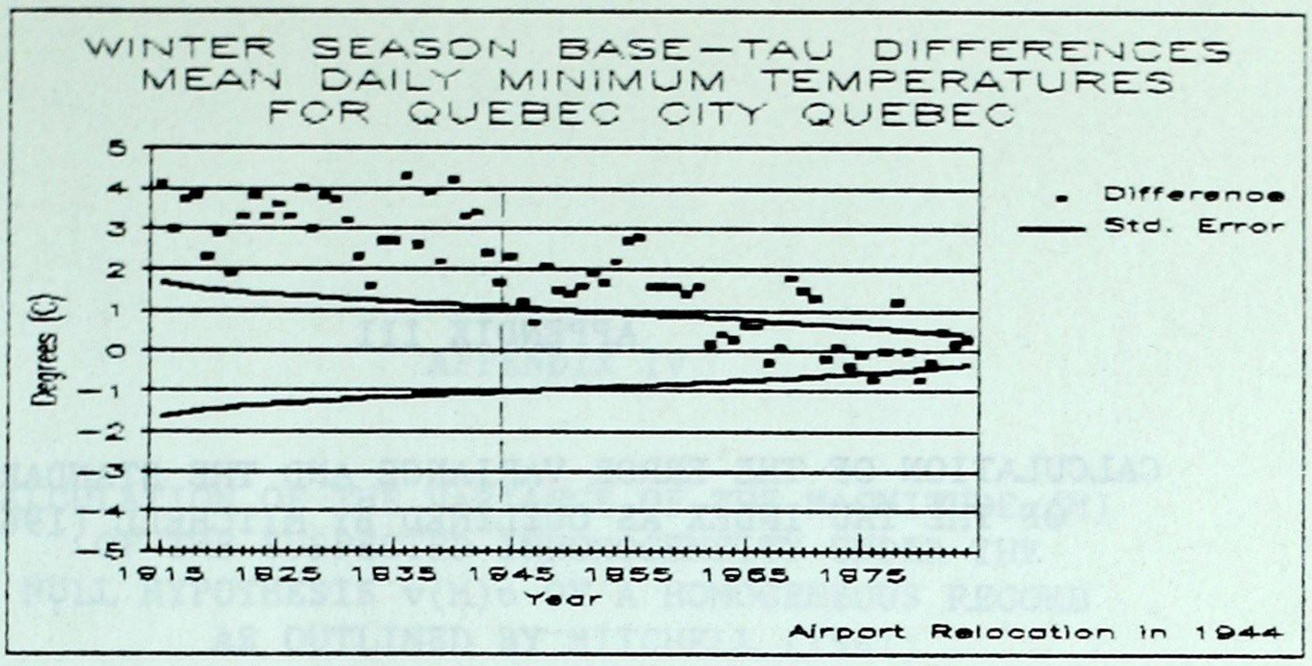
1915 1925 1935 1945 1955 1965 1975
Year
Airport Relocation in 1944


WINTER SEASON BASE—TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Difference
Std. Error
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1915 1925 1935 1945 1955 1965 1975
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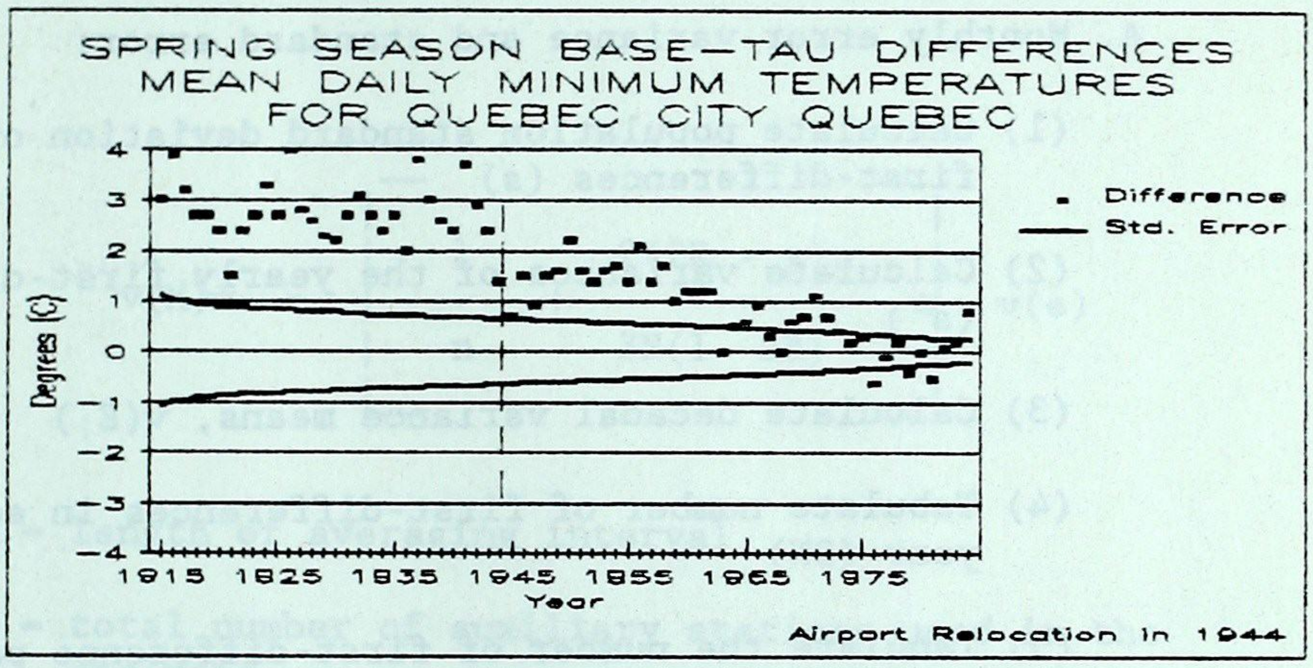
SPRING SEASON BASE—TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Difference
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Year
1915 1925 1935 1945 1955 1965 1975
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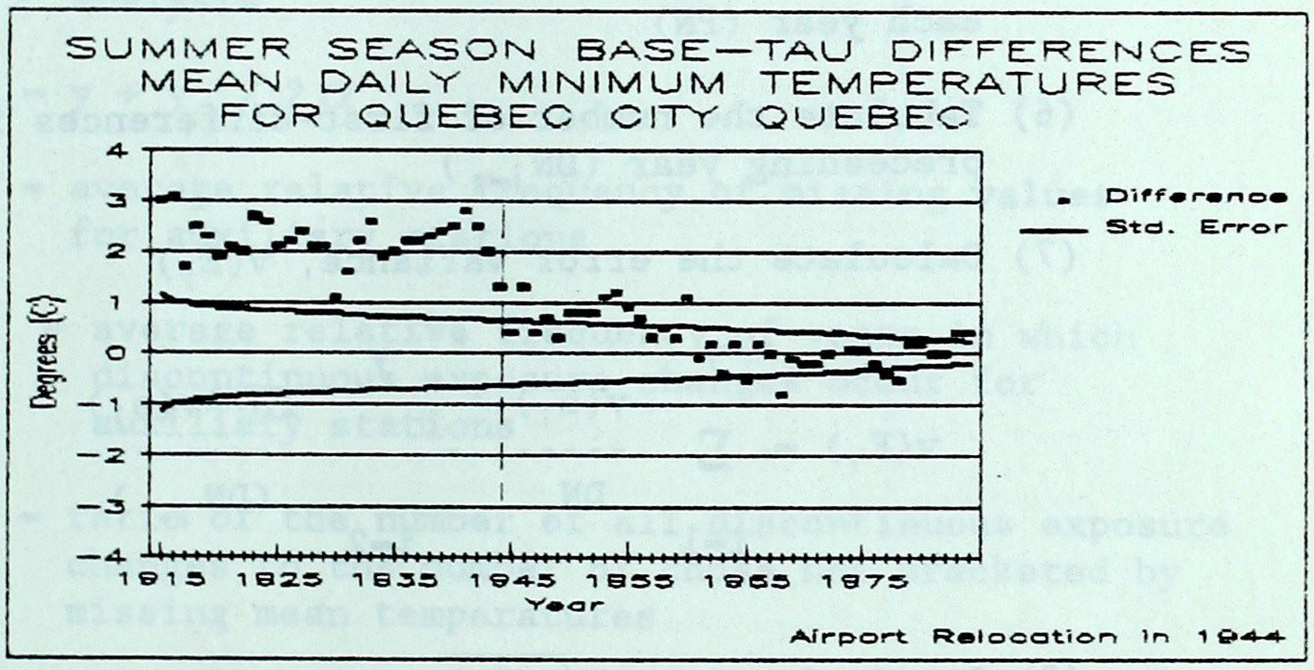
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MEAN DAILY MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Difference
Std. Error
Degrees (C)
Year
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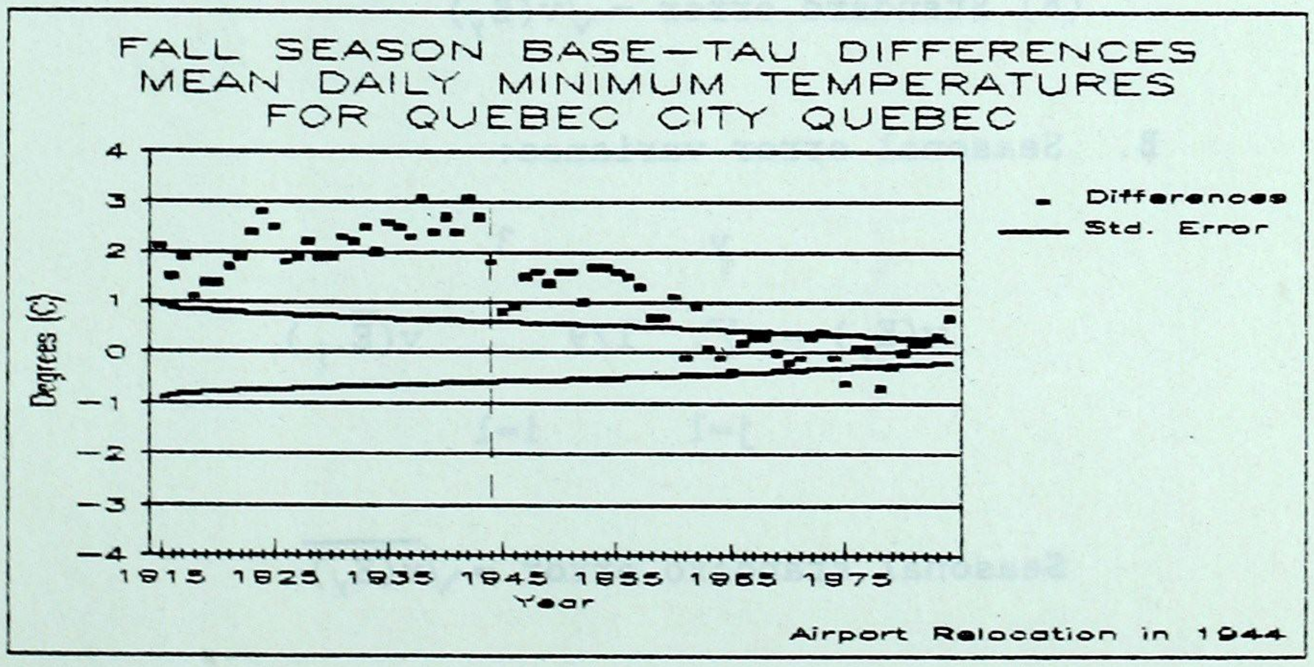
Airport Relocation in 1944


FALL SEASON BASE—TAU DIFFERENCES
MEAN DAILY MINIMUM TEMPERATURES
FOR QUEBEC CITY QUEBEC
Differences
Std. Error
Degrees (C)
Year
1915 1925 1935 1945 1955 1965 1975
Airport Relocation in 1944

APPENDIX III

CALCULATION OF THE ERROR VARIANCE AND THE STANDARD ERROR OF THE TAU INDEX AS OUTLINED BY MITCHELL (1961)

A. Monthly error variance and standard error:

(1) Calculate population standard deviation of yearly first-differences (s)

(2) Calculate variances of the yearly first-differences (s^2)

(3) Calculate decadal variance means, $v(E_i)$

(4) Tabulate number of first-differences in each year (DN)

(5) Tabulate the number of first-difference pairs in each year (PN)

(6) Tabulate the number of first-differences in preceeding year (DN_{i-1})

(7) Calculate the error variance, $v(E_y)$

$$v(E_y) = \sum_{i=1}^{y} \frac{v(e_i)}{DN_i} - \sum_{i=2}^{y} \frac{PN_i * v(e_i)}{(DN_{i-1})}$$

(8) Standard error $= \sqrt{v(E_y)}$

B. Seasonal error variance:

$$v(E_y) = \sum_{j=1}^{y} 1/9 \sum_{i=1}^{3} v(\bar{E}._j)_i$$

Seasonal standard error $= \sqrt{v(E_y)}$

APPENDIX IV

CALCULATION OF THE VARIANCE OF THE MAGNITUDE (M) OF THE SUSPECTED INHOMOGENEITY UNDER THE NULL HYPOTHESIS v(M)o OF A HOMOGENEOUS RECORD AS OUTLINED BY MITCHELL (1961)

$$v(M)_o = \left[\frac{1}{n} + \frac{2(2R - y)n}{3N(1 - 2R)} \right] v(e)$$

n = length of averaging interval

N = total number of auxiliary stations used in the analysis

$R = y + y' / 2\alpha$

y = average relative frequency of missing values for auxiliary stations

y' = average relative frequency of years in which discontinuous exposure changes occur for auxiliary stations

α = ratio of the number of all discontinuous exposure changes to the number of those not bracketed by missing mean temperatures