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Cloudiness and wind speed as factors in a climatic anomaly

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ABSTRACT

Since 1940, Calgary's mean annual temperature has declined 0.3 °C from the mean value established during a warmer era, 1905–1940. However, the length of the frost-free period increased from an average of 109 days in the warmer period to 119 days in the cooler one. These changes are underscored by an advance of the probable date of the last spring frost, and a delay of the probable date of the first frost of autumn. Probabilities are computed for various critical frost dates. The belief is expressed that the discrepancy of a longer growing season in the face of declining growing season temperature is related to an observed increase in mean cloudiness during the growing season. It is also demonstrated that strong winds could have been a factor in promoting the anomaly.

1. Introduction

The case for a cooling of the earth's climate during the past 40 years has been amply documented (Lamb, 1975). Consequently, concern has been raised over the possible adverse effect which a cooling trend could have on the agricultural industry and world food production (Bryson, 1973). One such concern centers around the effect that a cooler earth could have on the length of the growing season. Kellogg (1978) estimated that if the summer temperature rose 1 °C, the growing season could increase by 10 days. The reverse might happen should the earth undergo an equivalent degree of cooling. In upper middle latitude climates where the growing season is already precariously short, a reduction in the length of the growing season could inflict unacceptable damage on agriculture. In some cases the cultivation of some food crops may have to be abandoned altogether on account of the new thermal reality.

However, before the correlation implicit in Kellogg's statement can be universally accepted, available data should be examined for empirical support. The report presented below represents one such examination. It is based on hourly temperature, cloud and wind data for Calgary (51 °N 114 °W) from 1885 to 1978. It is shown that although summer temperatures have steadily dropped in line with a similar decline in the average annual temperature, there has been a very substantial increase in the number of frost-free days since 1940. Although this trend does not entirely eliminate the fears of the food-growing industry with regard to a cooler earth, it does raise some doubts, however limited, on some of the assumed consequences of a cooler earth.

2. Temperature trends

Although the mean annual temperature for Calgary is 3.4 °C (C.M.S., 1971), it has fluctuated considerably over recent history. In 1918 and 1931 it reached a high of 5.4 °C. A low of 1.2 °C was recorded in 1887 and 1951. These fluctuations are part of longer-term trends of alternating warmer and cooler climates which have occurred in the last ninety years. Using a five-year running mean, the following regimes were isolated (Fig. 1).

(a) From 1885 to 1904, the climate was cool. The mean annual temperature was about 0.4 °C below average.

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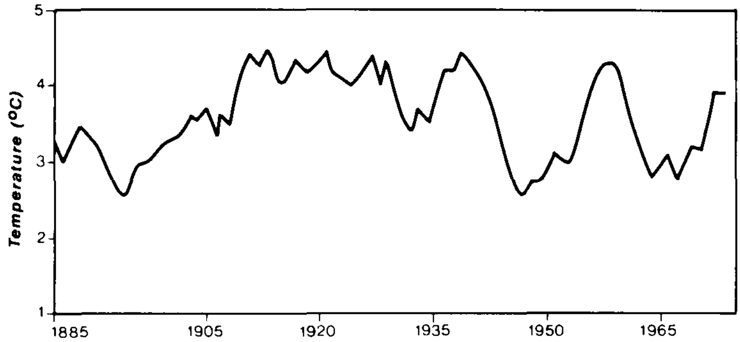

Fig. 1. 5-year running mean of average annual temperature for Calgary.

(b) From 1905 to 1940, a much warmer climate prevailed. Mean annual temperature was 4 °C, 0.6 °C above normal.
(c) From 1941 to 1955, temperatures dropped a full 0.7 °C from the high of period (b).
(d) A short-lived recovery occurred in the mid fifties but was quickly replaced by cooler weather.
(e) From about 1960 to the mid seventies cooler temperatures prevailed before the current, and perhaps short-lived recovery.[1]

All five movements are not statistically significant. Indeed, only when the data was grouped into two periods, namely a warmer period from 1905–1940 (period I) and a cooler one from 1941 to 1978 (period II), did the contrast become statistically significant at the 0.05 significance level. Thus the temperature trends follow the pattern reported for parts of the northern hemisphere by Mitchell (1963), and confirmed by Lamb (1975). The mean annual temperature dropped from 3.7 °C in period I to 3.4 °C in period II. A similar reduction occurred during the growing season. Average temperature from May through September declined 0.3 °C, from 13.2° to 12.9° between the two periods. In addition, mean annual temperatures were more variable in period II than period I. Between 1941 and 1978 the standard deviation of the yearly mean temperature was 1.02 °C compared to 0.98 °C from 1905–1940. Temperatures in the growing season were equally variable. The standard deviation increased to 3.8 °C in period II from 3.1 °C in period I.

[1] Based on recent calculations of the effect of the significant increase in atmospheric CO_2 (Cess, 1980) this recovery may not be short lived.

3. Frost-free days

Because no growth of agricultural importance can occur when the temperature is near the freezing point (Chang, 1968), and because extensive crop damage may follow persistent sub-freezing temperatures, the length of the growing season is determined in part by the number of continuous frost-free days during the year. Calgary's frost-free period normally extends from the latter part of May to early September. The average number of frost-free days for the area is 106 days (C.M.S., 1971), although there is reason to believe that that figure is an underestimate. A minimum of 72 days occurred in 1902. The maximum ever recorded was 156 in 1940.

It appears, however, that there have been significant shifts in the length of the frost-free period since records began. The upward trend of the series (Fig. 2) underscores a steady increase in the number of continuous frost-free days between 1885 and 1978. In period I, the average length of the variable was 109 days. In period II it rose to 119 days. This net gain of 10 days is statistically significant at the 0.05 significance level.

The improvement was made because the average date of the last spring frost advanced 5 days from May 27 to May 22 (Fig. 3) while that of the first frost of autumn retreated 5 days from September 7 to 12 (Fig. 4). In period I, the probability that the last frost of the spring will occur on or after May 27 was 0.5, now it is 0.42. Similar reductions have occurred at almost all dates although the chance of frost occurrence beyond mid June increased

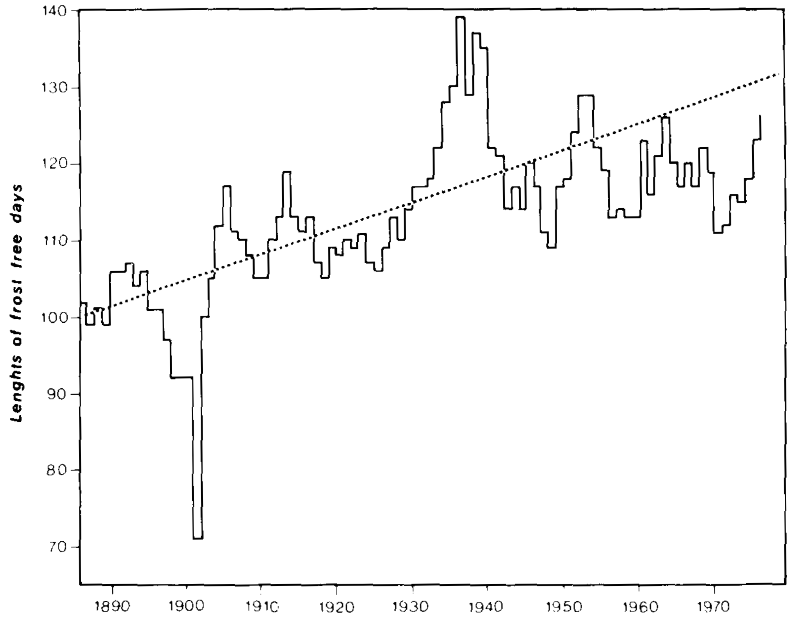

Fig. 2. Trend in the length of frost-free days.

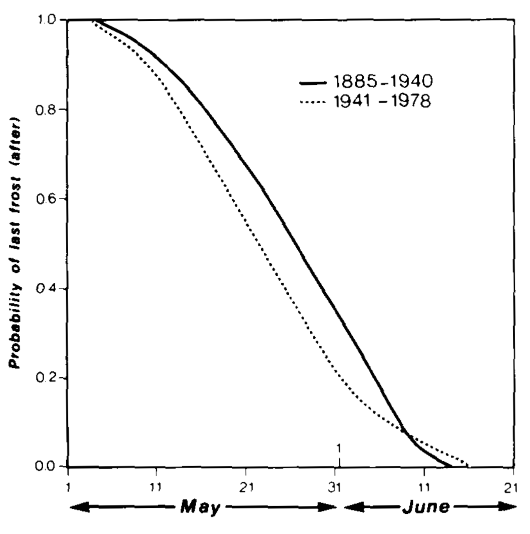

Fig. 3. Probability (cumulative) of occurrence of last frost in the spring in period I (1885–1940) and period II (1941–1978).

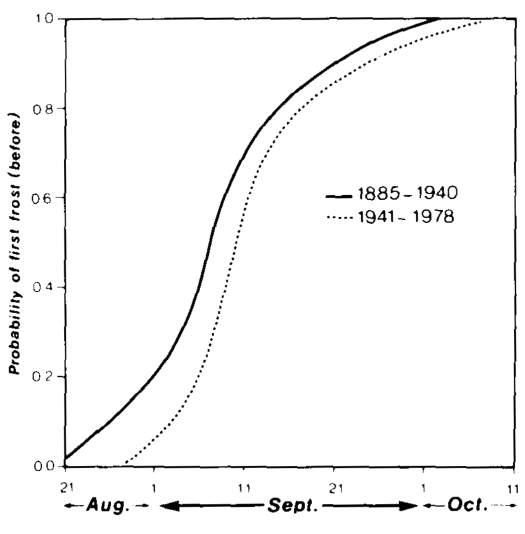

Fig. 4. Probability (cumulative) of occurrence of first frost in autumn in periods I and II.

slightly. The improvement in autumn is equally impressive. The best gains have been made early in the season where the chance of frost before the third week of August has virtually disappeared.

The increase in frost-free days has been accompanied by a gain in variability. In period I, the standard deviation was 14 days compared to 15.5 days in period II.

4. Possible causation

The foregoing analyses point to an apparent anomaly, namely, the existence of a longer growing season in a period of declining summer and annual temperatures in Calgary. At this point in the investigation the assumption is made that the phenomenon is a local one hence the search for a physical explanation of the apparent contradiction will be based on local rather than regional or global events.

The decline in mean annual temperature since 1940 came as a result of a drop of 0.5 °C in the mean daily maximum temperature during the growing season. During the same period the minimum temperature increased by about 0.2°C. Consequently, any factors that explain the increase in minimum temperature should provide a reasonable explanation for the decrease in maximum temperature. The possible impact of three physical factors which have potential to create the anomaly are now explored.

4.1. *Station relocation*

Temperature changes of the magnitude suggested by these figures can occur when stations are relocated or when the method of observation is changed or both. There is nothing in the station history that indicates that there has been a change in the method of observation or in the exposure of the instruments in the period covered by the analysis. Between 1885 and 1931, the observing station was located near the city where urban influence could be a factor in promoting increasing temperatures. A role for urbanization in the temperature regime is disputed on the following grounds:

(i) At 81,000 (1931) the population of the city may have been too small to justify significant urban influence. Moreover, it is doubtful that an urban effect would be present in the warmer months of the year, the period of interest in this study. Chandler (1962) showed that even in a city the size of London, urban temperature anomalies are subdued during the summer.

(ii) The 1881–1931 regime is classified under period I when the average length of the frost-free period was significantly lower than it is today. If an urban effect was present then night time temperatures should have been higher thereby reducing the chance of late spring and early autumn frost.

In 1931 the station was moved from the city to the Municipal Airport. Its present location at the Calgary International Airport was effected in 1939. The former is the more drastic of the two relocations because it involved (a) a move to a more rural site and (b) a move to higher ground. There is an elevation difference of about 20 m between the two sites. However, it is apparent that no break in trend of statistical significance coincided with that date, a fact which may be due as much to smoothing as to the lack of significant shift in the regime. In any event, since the anomaly did not occur during that period, interest in it is marginal to the study. The later relocation did not disrupt the regime because of similarity in the two airport sites. When the daily maximum and minimum temperature of overlapping records of the two sites were compared for the growing season, a difference of less than 0.1 °C in the mean value of each of the variables was obtained. That difference was not statistically significant.

From these observations and deductions it is not unreasonable to believe that station history is not a major factor in the discrepancy. Consequently we have looked elsewhere for an explanation for the paradox.

4.2. *Other factors*

It is equally unlikely that the improvement in the length of the frost-free period occurred because of a displacement in the mean position of the Arctic air mass (Nkemdirim and Benoit, 1975) because the frosts which mark the beginning and end of the growing season were not of the persistent variety, nor were they advective. 76% of the events occurred in isolation, 86% occurred at night and 80% occurred when wind speed was less than 10 km/h. It appears therefore that these frosts were associated with nocturnal radiative cooling. Consequently, the reason for the anomaly may lie in the behavior of those variables which encourage radiative frosts at night.

It is a well-known meteorological fact that clear skies and light wind encourage nocturnal radiative cooling (Nkemdirim, 1978). Therefore, if there is a significant increase in cloudiness or strong winds, or both during the growing season, counter radiation from the cloud base and convective

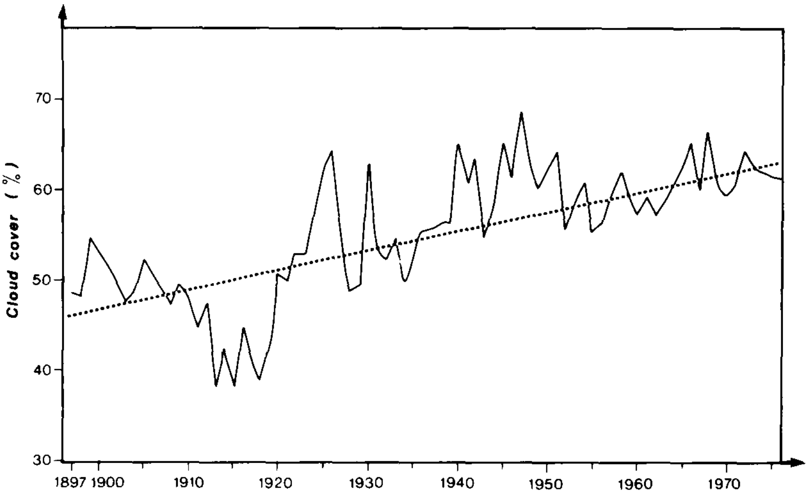

Fig. 5. Variation in mean growing season cloudiness and its trend.

stirring of the atmosphere near to the ground may result in an energy redistribution which may be sufficient to reduce the risk of frost during the frost-sensitive periods of late spring and early autumn when only a small drop in minimum temperature may be all that is required for frost to occur.

(i) *The role of cloudiness.* The trend in the length of frost-free days appears to have been replicated in total cloudiness during the growing season (Fig. 5). From 1885–1940 cloudiness averaged 50% in Calgary. Between 1941 and 1978 it increased 11 points to 61%. Both the trend and the increase are statistically significant at the 0.05 significance level. A positive correlation of 0.35, again significant at the same level, was obtained between cloudiness and the frost-free period. The correlation is strong enough to warrant a conclusion that the increase in cloud cover is a factor in the anomaly. The correlation coefficient is even higher (r = 0.52) when the association is restricted to the first two weeks in May and the equivalent period in October.

(ii) *The role of wind speed.* Continuous records of wind speed did not begin until 1931. Consequently it was not possible to compare the mean wind speed over the two periods. It appears, however, that the mean wind speed during the growing season was stronger in period II than the small time period of record prior to 1940 (Fig. 6). When wind speed was included in the correlation,

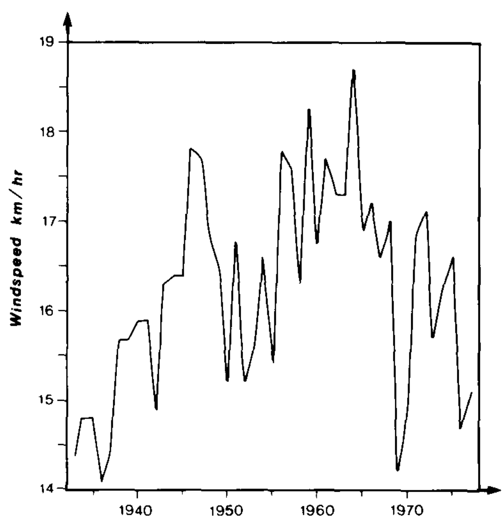

Fig. 6. Variation in mean growing season wind velocity (1931–1978).

the multiple correlation coefficient increased to 0.43 for the growing season as a whole and 0.58 for early May and October. The gain in the size of the coefficient in the former correlation was significant at the 0.05 significance level while the increase in the latter was not. In view of these, it may be surmised that the presence of a strong wind reinforced the role of a cloud cover in promoting a longer growing season in period II.

5. Discussion

Although the subject has been treated from a local standpoint, the results of the analyses could have global implications. However, such implications can only be verified from a comprehensive study of changes in the growing season of upper middle latitude climates whether on a regional or a global scale. In spite of the justifiable tendency in some quarters to treat Calgary's climate as a special case (Longley, 1977), two developments in the climate of the earth encourage the extrapolation of these results beyond the local level. Firstly, the analysis shows conclusively that Calgary is experiencing a decline in its mean annual temperature since 1940. Secondly, the observation on cloud cover appears to be part of a general trend in North America. Machta and Carpenter (1971) reported a significant increase in cloud cover in the United States since 1965. There have also been exceptionally large increases in some cloud types. In Denver, for example, the amount of high cloud nearly doubled in the period covered by the report. There is therefore good reason to believe that the Calgary anomaly may be replicated elsewhere.

Clouds have featured prominently in discussions and models of climate and its change (Möller, 1963; Sellers, 1969). They are seen as either aiding the cooling process by reflecting solar energy or encouraging warming by reinforcing the atmospheric greenhouse effect or both. The balance between the two potential effects has never been satisfactorily resolved. This paper appears to suggest that the role of an increased cloud cover may be a selective one. While it may not prevent long-term cooling, it may help prolong the frost-free period.

Although there has been a real increase in the number of frost-free days in Calgary in the face of declining mean growing season temperature, this does not necessarily represent an improvement in the agricultural climate. In spite of a longer growing season, temperature may not be warm enough for the attainment of the heating level required for crop maturation. Thus a cooler temperature may well result in hardship to the industry in spite of a longer growing season.

6. Conclusion

This paper has intentionally left undiscussed the possible cause of the trends in mean temperature and cloudiness. These matters have been the subject of some speculation (Lamb, 1975; Machta and Carpenter, 1971) and, not surprisingly, lack of agreement. It does however discuss one possible effect of these trends. It appears from the results that the correlation implicit in Kellogg's statement is not borne out by empirical data obtained from Calgary. This raises some doubt about the use of simple argument to predict the consequence of climatic change.

The growing season has been narrowly defined in this paper. It is not unusual in the prairies for the fate of crops to be determined by factors such as the precipitation regime before and during the growing season, and the disposition of soil moisture. In an increasingly variable climate, the length of the frost-free period is only one determinant, amongst many, of the health of the agricultural industry.

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ОБЛАЧНОСТЬ И СКОРОСТЬ ВЕТРА КАК ФАКТОРЫ В КЛИМАТИЧЕСКОЙ АНОМАЛИИ

После 1940 г. среднегодовые температуры в Калгэри упали на 0,3°C по отношению к средней величине, установившейся в более теплый период 1905-1940 г.г. Однако длительность периода без заморозков увеличивалась со 109 дней в более теплый период до 119 дней в современный более холодный период. Эти изменения подчеркиваются продвижением вероятной даты последнего весеннего заморозеа и запаздыванием вероятной даты первого заморозка осенью. Вычислены вероятности для различных критических дат заморозков. Высказано предположение, что несоответствие более продолжительного вегетационного периода уменьшению температуры в это время связано с наблюдаемым увеличением средней облачности в течение вегетационного периода. Показано также, что сильные ветры могут быть фактором, усиливающим этот парадокс.