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Climatic classifications of the Prairie Provinces of Canada

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ABSTRACT

Various climatic or related classifications have been produced for the Prairie Provinces of Canada, often based on Köppen's or Thornthwaite's system. Many of these classifications were discipline-oriented and were based on predetermined climatic-parameter class limits or included subjective biases about vegetation or physiographic features. Examples of these classifications are given along with their uses and limitations for the area as a whole. Recently, a factor analysis approach was used to establish summer climatic zones for the forested and agricultural fringe areas of the Prairie Provinces and was extended for the whole area on a more limited scale. This approach involved the use of over 300 stations for the years 1961 to 1970, each with a matrix of 22 independent variables based on daily temperature and precipitation records for the months of May to September. These variables were used as input for the factor analysis to develop eigenvalues and eigenvectors for each station, and factor scores. The factor scores then became input for a hierarchical profile grouping procedure to delineate stations having similar summer climatic regimes. Discriminant analysis was then used to test whether the groups were significantly different, to establish the degree of stability within and between groups, and to position the boundaries between groups. This approach provides a more rational statistical process of analyzing climatic data and more efficiently delineates climatic regions than the more traditional *a priori* climatic classifications.

INTRODUCTION

Classification is a process basic to all sciences. The goal of any climatic classification is the grouping of a large number of local climates into a few climatic regions that are reasonably homogeneous and can be defined in terms of numerical climatic data. Such boundaries should also have relevance in terms of limits of plant communities, soil groups, and other natural features. Thornthwaite (1943) stated that "the purpose of a climatic classification is to provide a concise description of the various climatic types in terms of the truly active factors", primarily those of moisture and heat. A classification should not only differentiate between types, but should also show the relationships among them. At the same time it should supply the framework for differentiation of the innumerable microclimates that make up a climatic type. Thornthwaite holds that no matter how numerous or complex the techniques of this field of study become, one major problem will remain: "Climate is an extremely complex phenomenon, and any classification of it necessitates great over-simplification and involves the risk of serious error."

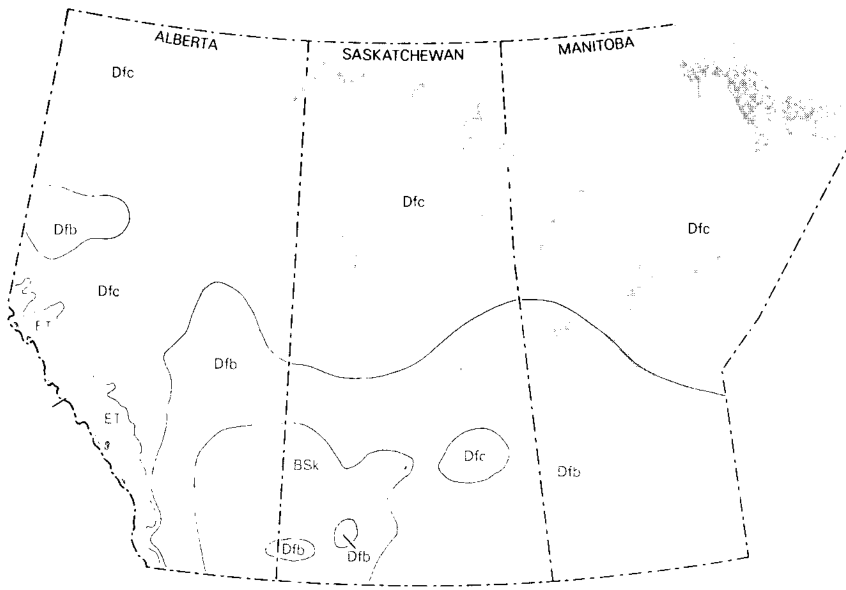
Climatic classification originally was the concern of plant geographers and biologists such as Alexander von Humboldt, Alphonse de Candolle, Carl Linsser, A. Grisebach, and Wladimir Köppen (see Thornthwaite 1943; Hare 1951; Thornthwaite and Hare 1955). Köppen, who is often referred to as the father of modern climatic classification, presented his first classification in 1900 and continued to modify it until his last paper appeared in 1936. He accepted the hypothesis that climate is reflected by the distribution of vegetation. In his initial and subsequent classifications he attempted to delineate different vegetation boundaries by means of quantitative averages of climatic parameters.

Climatic classification has assumed various forms relating directly to the level of sophistication and technology of the techniques imposed by climatic analysts. Classifications have ranged from broad global zones to very specific areas on a local scale. Today there are over a score of different schemes of classification of world climates (Trewartha 1968), but those of Köppen (1900, 1918, 1924, 1931, 1936) and Thornthwaite (1931, 1933, and 1948) are probably the most familiar in North America and noteworthy because they are quantitative systems that use numerical values for defining the boundaries of climatic groups.

The present paper attempts to discuss some of the climate or climate-related classifications developed for or which include the Prairie Provinces of Canada, and to present a classification of the summer climate of the area based on the factorial analysis approach.

CLIMATIC CLASSIFICATIONS FOR THE PRAIRIES AREA

A number of climatic classifications are available for the Prairie Provinces or portions of the area. Some of these have been based on features of general climate rather than on quantitative values for different climatic parameters. Examples of such classifications for the area are those of Taylor (1947) and Kendrew and Currie (1955). Köppen determined five major climate types roughly corresponding to five major vegetation regions of the earth. These he further subdivided on the basis of other climatic factors. Köppen's classification has often been applied to all or portions of the Prairie Provinces on the basis of different 30-yr normal periods (Canada Department of Mines and Technical Surveys 1957; Haurwitz and Austin 1944, Longley 1970, 1972; Rheumer 1953; Richards and Fung 1969). Fig. 1 shows the area using Köppen's classification based on data for the 1921-1950 period (Canada Department of Mines and Technical Surveys 1957, Plate 30). Most of the area falls into Köppen's Humid microthermal climates, *D*, but portions of southeastern Alberta and southwestern Saskatchewan fall into his Dry climates (BSk Middle latitude steppe or Cold steppe). The forested area of the *D* climate falls into his *Dfc* region (Sub-Arctic or Cold "snowy forest" climate). The remainder of the *D* climate, in the parkland and prairie area, falls into his *Dfb* region (Humid continental, cool summer, no dry season, or Cold "forest", cool summer). Some mountain areas of Alberta belong to the Polar climates *E* (*ET*-Tundra and *EF*-Ice Cap), but the information necessary for their detailed classification is lacking (Longley 1972). Others, such as Rheumer (1953) and Trewartha



Source: Canada Department of Mines and Technical Surveys 1957

Dfc Sub arctic

Dfb Humid continental, cool summer, no dry season

BSk Middle latitude steppe

ET Tundra

EF Ice cap

Fig. 1 Climatic regions based on Köppen's classification and data for the 1921-1950 period

(1954, 1968), have modified Köppen's classification and applied them to this area. Rheumer's (1953) classification, which uses the climatic year concept, especially further subdivides Köppen's classification parallel to the Rocky Mountains in Alberta. Trewartha's (1968) most recent classification is so modified that he suggests that Köppen's name should no longer appear on it. Maps using Köppen's basic classification but with different climate periods and station data can show considerable variation (cf. Canada Department of Mines and Technical Surveys 1957; Haurwitz and Austin 1944; and Longley 1970). Maps of climatic regions, natural vegetation, and zonal soils from the Atlas of Saskatchewan (Richards and Fung 1969) show how closely such different classifications are related.

There are several weaknesses and limitations in the use of Köppen's system because of its complexity, the arbitrary nature in which the climatic numerical limits were chosen, its broad zonation, and lastly its empiricism; however, it does use simple temperature and precipitation values. He himself never regarded his classification as a finished product, and in every contribution to the subject he remarked on the need for classification having a more rational foundation (Thornthwaite 1943).

Thornthwaite attempted to solve some of the problems inherent in the Köppen scheme by basing his classification on precipitation effectiveness and thermal efficiency. In his first attempts Thornthwaite (1931, 1933) he assigned the major role to the moisture factor, and in his later attempt (1948) to potential evapotranspiration. His classifications were more sophisticated and rational and follow from the relationships among computed monthly or annual totals of actual evapotranspiration, water surplus, and water deficiency. In a later paper (Thornthwaite and Hare 1955) he noted that "any effective system of climatic classification in forest or grassland regions must necessarily seek to express this process (evapotranspiration) and to use it as the central parameter." Thornthwaite's system has many features that are better than the Koppen classification, but it is not easy to employ or to establish boundaries. Ellis (1938) used Thornthwaite's early precipitation effectivity and temperature efficiency formulae to help define the climate of the vegetation regions of Manitoba. Sanderson (1948) employed Thornthwaite's second system to establish climatic types for Canada, and Trewartha (1954) showed a map using this system. Each of the atlases for the three Prairie Provinces includes an example of moisture regions derived from Thornthwaite's formula involving annual moisture deficit and moisture surplus (Government of Alberta and University of Alberta 1969; Richards and Fung 1969; Weir 1960). These maps are usually based on the latest publication of Thornthwaite for computing potential evapotranspiration and water balance (Thornthwaite and Mather 1957).

Climatic classifications in more detail exist for the agricultural areas (Bowser 1967; Chapman and Brown 1966; Ouellet and Sherk

1967; Watts 1968), but like many other classifications they provide only one or two zones for the forested area, which constitutes approximately three-quarters of the geographical area of the Prairie Provinces (Rowe 1972). Watts (1968) and Chapman and Brown (1966) provided thermal and moisture classes for the area using Thornthwaite's system and combined the two classes to develop climatic regions or climatic capability classes for agriculture. In both these classifications bias is created in attempting to set the class limits. Bowser's (1967) map of Alberta delineates areas that have similar climatic characteristics for cropping purposes based on a combination of climatic factors, including the limiting factors of summer heat units, frost-free periods, days between peak summer rainfall and first fall frost, and lack of moisture. Ouellet and Sherk's (1967) map of plant hardiness zones gives climatic zones based on an "index of suitability" developed from several climatic factors including temperature, frost-free period, rainfall, maximum snow depth, and maximum wind gust in a 30-yr period. Ecologically significant site regions for Manitoba-Saskatchewan that incorporate general climatic information were developed by Zoltai *et al.* (1967). A recent preliminary classification of wetlands also reflects regional differences in climate (Zoltai *et al.* 1975). Mills (1970) discusses the development of six climatically significant soil regions in Manitoba and compares them with the classes of the equivalent portion of the preliminary soil climatic map of Canada (Clayton 1970). A detailed version of this map was published by the Canada Department of Agriculture (1972); a simplified version appears in the National Atlas (Canada Department of Energy, Mines and Resources 1973). This map presents soil temperature classes and soil moisture regimes and subclasses developed from a meagre network of soil temperature stations and largely derived soil moisture criteria. In most cases the boundaries of the various regional climatic areas have been made to coincide with established soil and physiographic boundaries; other limitations are indicated by Mills (1970). In this classification much of the forested zone falls into the cold cryoboreal soil temperature class, with more southern fringe forested areas falling into the moderately cold cryoboreal or cool boreal soil temperature classes. In the soil moisture classification most of the forested zone falls into the humid moist unsaturated regime with very slight water deficit, and the agricultural fringe, including the Interlake area of Manitoba and the Peace River area of Alberta, into the subhumid area with a significant water deficit. Water deficiency and potential evapotranspiration values using Thornthwaite's method were also developed by Laycock (1967) for the Prairies. Longley (1972) used the percentage of years with a 20-cm moisture deficit to help define the moist and dry portions of the steppe zone in southeastern Alberta and southwestern Saskatchewan. Shaykewich (1971, 1974) has also been working towards a new climatic classification for agriculture in southern Manitoba and has developed maps for frost occurrence, corn heat units, seasonal precipitation, and soil water deficit. His map of climatic regions for agriculture is based on the variables of average soil water deficit on August 13 and average number of frost-free days above $0^{o}C$ (Shaykewich 1974).

FACTOR ANALYSIS APPROACH TO CLIMATIC CLASSIFICATION

Steiner (1965) was the first to use the factor analysis approach for climate. McBoyle (1971, 1972) used the approach based on principal component analysis for climatic classifications of Australia and Europe. The factor analysis approach was also used in preliminary classification studies of the summer climate of Alberta or portions thereof (MacIver 1970; MacIver *et al.* 1972; Powell and MacIver 1975a, 1976). Miller and Auclair (1974) and Nicholson and Bryant (1972) have employed a factor analytic approach to show relationships between climate and forestry. The application of factor analysis to climatic classifications seems appropriate because it allows for the identification of the basic underlying patterns that control any "regionalization" within a complex set of multivariate data. The approach provides a rational statistical process of analyzing climatic data using as input the selected climatic variables compiled for each station, giving *a posteriori* classes rather than the traditional *a priori* climatic classifications of Köppen, Thornthwaite, and others.

A FACTORIAL SUMMER CLIMATOLOGY FOR THE PRAIRIE PROVINCES

A climatic classification was developed for the forested and agricultural fringe areas of the Prairies based on daily temperature and precipitation records from 303 stations, including many forestry lookout stations, for the months May to September for the years 1961 to 1970. Details of the study are provided by Powell and MacIver (1977), with earlier phases of the study briefly reported in conference publications (Powell and MacIver 1975a, b, c). A matrix of 22 independent variables that explain most of the variation between stations was employed. The variables used were elevation, longitude, latitude, mean monthly temperatures for May to September, monthly precipitation totals for May to September, frequency of days with a minimum temperature $-2.2^{\circ}C$ in the months May to September, and water deficiency values for the months June to September. Water deficiency values were calculated using Thornthwaite's water balance technique (Thornthwaite and Mather 1957) adjusted for a 7-month period from April to October, assuming a soil moisture storage level of 101.6 mm (4 in.) per year by the end of March.

For many of the forest fire weather stations it was necessary to generate missing values for temperature and precipitation, especially for portions of May and September when they are often closed. Third-order polynomial regression equations were used to compare a complete nearby station to a station with incomplete data. If the F-ratio was not significant at the 95% confidence level, the incomplete stations were eliminated from further analysis. The complete sets of input data for the variables were then used in a factor analysis to develop eigenvalues and eigenvectors for each station. Only eigenvalues greater than unity were considered and only if they explained at least 5% of the total variance (King 1969). The coefficients generated in a varimax rotated factor matrix, in combination with the 22 input variables per station, give weighted indices per station in the form of factor scores. Only those input variables with a coefficient of $> \pm 0.700$ in the factor scores were considered statistically significant variables.

Table 1
THE NINE FACTOR SCORES WITH THE PERCENTAGE EXPLAINED VARIANCE AND THE VARIABLES THEY DESCRIBE

Factor	% Variance Explained	Variable Description
1	18.7	May Temp. >-2.2°C, May Temp., June Temp. >-2.2°C
2	16.3	Longitude, Elevation, July temperature
3	13.0	July Prec., Aug. Prec., Aug. Water Def.
4	9.7	Latitude, May Prec.
5	7.4	June Water Def.
6	6.8	September Prec.
7	6.2	July Temp. >-2.2°C
8	6.1	Aug. Temp. >-2.2°C
9	5.3	June Prec.
Total	89.3	

Temp. = temperature °C; Prec. = precipitation; Def. = deficiency.

The analysis indicated that there were nine factor scores, each of which explained at least 5% of the total explained variance and had an eigenvalue >1.00. These nine factors explained 89.3% of the variance and included 16 of the original 22 input variables (Table 1). The original matrix of 6,666 items of climatic information (an input matrix of 303 x 22) has at this point been reduced to nine factors and 16 variables. The independent normalized factor scores for each station are then used for a hierarchical profile grouping procedure that groups the stations by means of their climatic characteristics. This program compares a series of score profiles and progressively associates them into groupings in such a way as to minimize an overall estimation of variation within the groups. The grouping procedure indicated 26 as the "optimal" number of groups with an accep-

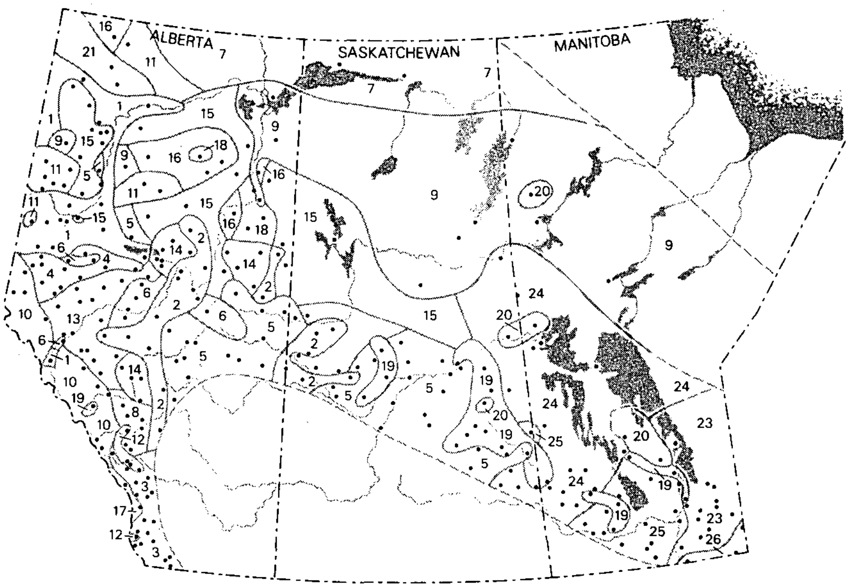
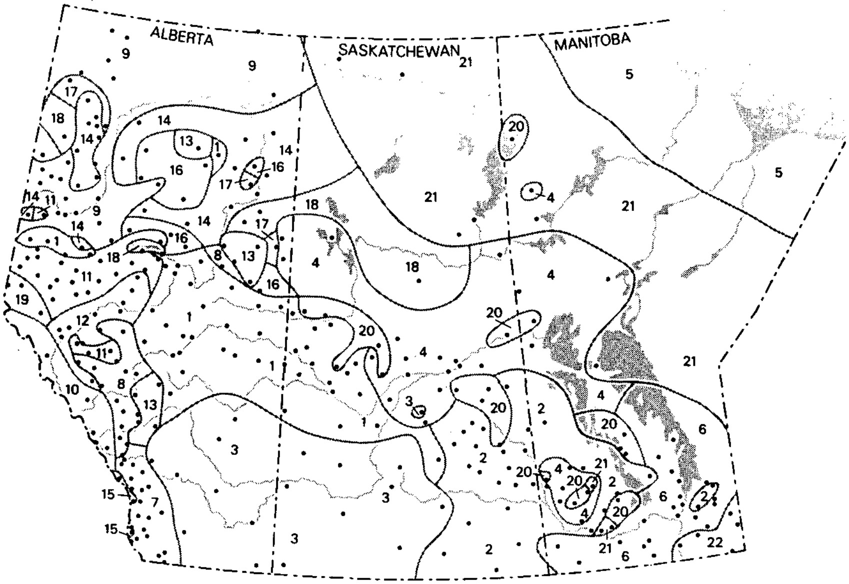


Fig. 2 Twenty six climatic groupings for the forested regions of the prairie provinces

table (in this case 15%) minimum accumulated-error-loss. Multiple discriminant analysis was then used to test the significance of the factor analysis and heirarchical grouping outcomes and to identify the major discriminating variables between groupings. The discriminant analysis indicated that the 26 climatic groups were separate and mutually exclusive. It also showed that the "rule of thumb" used in the factor analysis procedure of a cutoff limit of > 1.00 for the eigenvalues if they explained at least 5% of the variance was valid; however, it did show that factor score 8 (August frequency of days > -2.2°C) was not a major significant discriminating variable between groups. The statistically important variables between groups were used to help position the boundaries between the groupings. Fig. 2 shows the 26 climatic groupings with boundary placement using significant-between-group variables (the numbers on the figure have no significance except that they relate to groups of the hierarchical program). In a few cases stations isolated from their groups



Numbers relate to groupings of the hierarchical program

Fig. 3 Twenty two climatic groupings for the prairie provinces

were included in the dominant surrounding group if the hierarchical grouping procedure indicated a close relationship. The means and interstation variability for each of the major significant discriminating variables for the 26 groupings are given elsewhere (Powell and MacIver 1977).

In order to obtain a climatic classification for the whole of the Prairie Provinces, 27 stations were selected to represent the dominantly agricultural belt, and Churchill was added for northern Manitoba. The May to September, 1961-1970 data from these stations were added to the data bank for the 303 stations in the forested and agricultural fringe area; a factor analysis was carried out using only the variables elevation, longitude, latitude, and mean monthly temperature and mean monthly precipitation for the months May to September. The additional limiting factors of frequency of days with a minimum temperature > -2.2^{o}C and water deficiency were therefore not used in this analysis. Fig. 3 shows the map of the Prairies with 22 climate groupings, the number of groups which was indicated as "optimal" in this factorial analysis. With one less grouping (21), groups 8 and 13 would combine, and with one more group (23), the stations of Upper Hay River and Watt Mountain in northwestern Alberta would be separate from group 9.

From the comparison of Figs. 2 and 3, Churchill and the Hudson Bay Lowlands, as expected, are indicated as a separate group. Most of the agricultural zone not included in Fig. 2 forms one grouping (3), while southeastern Saskatchewan and southwestern Manitoba are joined with the areas to the north already present in Fig. 2. Many of the groupings indicated in Fig. 2 are still present in Fig. 3, although group boundaries are often changed, losing or picking up a few stations. Group 1 of Fig. 3 has become much broader. Some of the changes are a result of fewer groups indicated, but probably the additional limiting variables used in computing Fig. 2 play a role in further differentiating between groups, especially because in the earlier analysis many of these variables were highly significant in the factor scores.

DISCUSSION AND CONCLUSIONS

Factor analysis followed by hierarchical grouping analysis lends itself to numerous classification uses. Depending on the purpose, the user may select the desired level of detail required from a series of groupings, because this technique not only differentiates between groups but shows the relationships among them. If a broader classification is required, the hierarchical program indicates how the groups combine with each other to give fewer groupings. The classification system is therefore very adaptable to providing the user with the required level of resolution. The factorial approach also indicates which are the important variables in distinguishing between climatic groupings; this alone should be of value to the potential user in making decisions about certain areas.

There is a definite paucity of stations in northern Manitoba and Saskatchewan and northeastern Alberta in the present study. However, relatively few groupings were indicated in these areas, suggesting that a greater density of stations would not basically change the map or groupings, although there would obviously be some refinement of the boundaries. In fact, any time the data base is changed by adding or subtracting stations, it would be expected that the groupings and their boundaries would change. This makes the system very flexible and gives it a wide utility, but is a drawback when compared with the *a priori* classifications that employ stable class limits to set group boundaries. However, inherent in this classification are some basic assumptions, typical of any classification scheme, whether *a priori* or *a posteriori*. The selection of the original climatic variables is left to the discretion of the investigator and his estimate of their significance in adequately characterizing the climate of an area or season. Secondly, it is assumed that the number of stations utilized and their distribution is adequate to represent the study area, and that the data do not include inherent observational or reporting errors. Thirdly, each station may or may not be representative of its surrounding area. Fourthly, in this study it was shown that a 10-yr period at selected stations was adequate to describe the summer temperature and precipitation regime compared with the most recent 30-yr period; therefore, stations with only a short period of record were accepted for inclusion in the study. In accepting a classification, the period of data gathering must always be considered because of the possibilities of climatic change taking place. However, with the present classification, provided such changes are experienced throughout the area, the groupings should remain relatively the same because there are no class limits, as in the *a priori* systems. Also, as McBoyle (1972) mentioned, there is little point comparing a factor analytic regionalization for a certain time-period with a Köppen-type classification for a different time-period. However, one valid general comparison can be made: where Köppen's classification (Fig. 1) indicates only broad classes for the Prairie Provinces, the present factorial classification adequately subdivides the area, especially the forested zones of the region, into many classes, which was the main objective of the study. The factorial classification approach should therefore be a valuable tool in resource decision making.

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References

BOWSER, W.E., 1967: *Agro-climatic areas of Alberta.* Can. Dep. Energy Mines Resour., Surv. Mapping Br. Ottawa. 1 map with text.

CANADA DEPARTMENT OF AGRICULTURE. 1972: *Soil climates of Canada.* Res. Br., Soil Res. Inst., Cartogr. Sec. Ottawa. 1 map.

CANADA DEPARTMENT OF ENERGY, MINES AND RESOURCES. 1973: *Soil climate.* The National Atlas of Canada. Plate 43-44.

CANADA DEPARTMENT MINES AND TECHNICAL SURVEYS. 1957: *Atlas of Canada* (Plate 30: "Climatic Regions"). Geogr. Br. Ottawa.

CHAPMAN, L.J. and D.M. BROWN, 1966: *The climates of Canada for agriculture.* Can. Dep. For. Rural Dev., Can. Land Inventory. Rep. No. 3. 24 pp.

CLAYTON, J.S., 1970: *Characteristics of the agroclimatic environment of Canadian soils.* Proc. 8th Meeting Can. Soil Surv. Comm. Ottawa, Oct. 19-20.

ELLIS, J.H., 1938: *The Soils of Manitoba.* Manit. Econ. Surv. Board. 112 pp. and maps.

GOVERNMENT OF ALBERTA and UNIVERSITY OF ALBERTA. 1969: *Atlas of Alberta.* Edmonton, Univ. Alberta Press. 162 pp.

HARE, F.K., 1951: *Climatic classification.* Pages 111-134 *in* Stamp, L.D. and S.W. Wooldridge (Eds.). The London essays in geography. London, Longman, Green & Co.

HAURWITZ, B. and J.M. AUSTIN, 1944: *Climatology.* New York, McGraw-Hill Book Co.

KENDREW, W.G. and B.W. CURRIE, 1955: *The Climate of Central Canada.* Queen's Printer, Ottawa. 194 pp.

KING, L.J., 1969: *Statistical analysis in geography.* Englewood Cliffs, N.J., Prentice-Hall. 288 pp.

KÖPPEN, W., 1900: Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt. *Geogr. Zeitschr.* 6:593-611, 657-679.

KÖPPEN, W., 1918: Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf. *Petermanns Mitt.* 64:193-203, 243-248.

KÖPPEN, W., 1924: *Die Klimate der Erde: Grundriss der Klimakunde.* Springer Verlag, Berlin & Leipzig.

KÖPPEN, W., 1931: *Grundriss der Klimakunde.* (2nd edit. of "Die Klimate der Erde"). Springer Verlag, Berlin & Leipzig.

KÖPPEN, W., 1936: Das geographische System der Klimate. *In* Köppen, W. and R. Geiger (Eds.). *Handbuch der Klimatologie* Vol. 1, Part C., Gebrüder Bornträger, Berlin.

LAYCOCK, A.H., 1967: *Water deficiency and surplus patterns in the Prairie Provinces.* Regina, Prairie Provinces Water Board. Rep. No. 13. 185 pp.

LONGLEY, R.W., 1970: Climatic classification for Alberta forestry. Pages 147-153 *in* Powell, J.M. and C.F. Nolasco (Eds.). *Proceedings, Third Forest Microclimate Symposium.* Kananaskis Forest Experiment Station, Seebe, Alta., Sept. 23-26, 1969. Can. Dep. Fish. For., Can. For Serv., Alta./ Territories Region, Calgary, Alta.

LONGLEY, R.W., 1972: *The Climate of the Prairie Provinces.* Environ. Can., Atmos. Environ. Serv., Climatol. Stud. No. 13. 79 pp.

McBOYLE, G.R., 1971: Climatic classification of Australia by computer. *Aust. Geogr. Stud.* 9:1-14.

McBOYLE, G.R., 1972: Factor analytic approach to a climatic classification of Europe. McGill Univ., Dep. Geography. *Climatol. Bull.* 12:3-11.

MacIVER, D.C., 1970: *Macroclimatic zonation in northern Alberta.* Univ. Alberta, Unpubl. M.Sc. thesis. 187 pp.

MacIVER, D.C., W.D. HOLLAND and J.M. POWELL , 1972: *Delineation of similar summer climatic regimes in central Alberta.* Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton. Inf. Rep. NOR-X-30. 32 pp.

MILLER, W.S. and A.N. AUCLAIR , 1974: Factor analytic models of bioclimate for Canadian Forest Regions. *Can. J. For. Res.* 536-548.

MILLS, G.F., 1970: *Climatically significant soil regions in Manitoba.* Pages 7-12 *in* Proc. 14th Annu. Manit. Soil Sci. Meeting, Univ. Manitoba. Dec. 9-10.

NICHOLSON, J. and D.G. BRYANT, 1972: *Climatic zones of Insular Newfoundland: A principal component analysis.* Environ. Can., Can. For. Serv. Publ. No. 1299. 13 pp.

OUELLET, C.E. and L.C. SHERK, 1967: Woody ornamental plant zonation. Pt. 3. Suitability map for probable winter survival of ornamental trees and shrubs. *Can. J. Plant Sci.* 47:351-358; and Map of plant hardiness zones in Canada. Can. Dep. Agric., Plant Res. Inst. Map and text.

POWELL, J.M. and D.C. MacIVER, 1975a: Climatic classifications of the Prairie Provinces: a new preliminary classification for the forested area of Alberta. Pages 99-111 *in* B.M. Barr (Ed.). *Western Canadian research in geography: The Lethbridge Papers.* Can. Assoc. Geogr., West. Div., B.C. Geogr. Ser. No. 21. Occas. Pap. Geogr. 124 pp.

POWELL, J.M. and D.C. MacIVER, 1975b: A factor analytic climatic classification of the forested areas of the Prairie Provinces. Pages 65-66 *in* Preprint Vol., 12th Agric. For. Meteorol. Conf., Am. Meteorol. Soc., Tucson, Ariz., April 14-16, 1975.

POWELL, J.M. and D.C. MacIVER, 1975c: A new climatic classification for the forested areas of the Prairie Provinces. (Abstr.). pp. 63-64 *in* CAG '75, May 26-30, 1975, Vancouver, B.C., Simon Fraser Univ., Dep. Geography.

POWELL, J.M. and D.C. MacIVER, 1976: *Summer climate of the Hinton-Edson area, West-Central Alberta, 1961-1970.* Environ. Can., Environ. Manage. Serv., North. For. Res. Cent. Edmonton. Inf. Rep. NOR-X-149. 43 pp.

POWELL, J.M. and D.C. MacIVER, 1977: *A summer climate classification for the forested area of the Prairie Provinces using factor analysis.* Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton. Inf. Rep. NOR-X-177. 51 pp.

RHEUMER, G.A., 1953: *Climate and climatic regions of Western Canada.* Univ. Illinois, Unpubl. Ph.D. thesis. 185 pp.

RICHARDS, J.H. and K.I. FUNG, 1969: *Atlas of Saskatchewan.* Univ. Saskatchewan, Saskatoon. Saskatoon, Modern Press. 236 pp.

ROWE, J.S., 1972: *Forest regions of Canada.* Environ. Can., Can. For. Serv. Publ. No. 1300. 172 pp.

SANDERSON, M., 1948: The climates of Canada according to the new Thornthwaite classification. *Sci. Agric.* 28:501-517.

SHAYKEWICH, C.F., 1971: *A new climatic map for agriculture in Manitoba.* Paper presented to Manit. Soil Sci. Soc. December. 10 pp. (mimeo).

SHAYKEWICH, C.F., 1974: *Climate of southern Manitoba as it relates to agriculture.* Manit. Dep. Agric. Publ. No. 546. 24 pp.

STEINER, D., 1965: A multivariate statistical approach to climatic regionalization and classification. *Tijdschr. K. Ned. Aardr. Gen.* 82:329-347.

TAYLOR, G., 1947: *Canada. A study of cool continental environments and their effect on British and French settlement.* London, Methuen & Co. Ltd. 524 pp.

THORNTHWAITE, C.W., 1931: The climates of North America according to a new classification. *Geogr. Rev.* 21:633-655.

THORNTHWAITE, C.W., 1933: The climates of the earth. *Geogr. Rev.* 23:433-440.

THORNTHWAITE, C.W., 1943: Problems in the classification of climates. *Geogr. Rev.* 33:233-255.

THORNTHWAITE, C.W., 1948: An approach toward a rational classification of climate. *Geogr. Rev.* 38:55-94.

THORNTHWAITE, C.W. and F.K. HARE, 1955: Climatic classification in forestry. *Unasylva* 9(2):51-59.

THORNTHWAITE, C.W. and J.R. MATHER, 1957: Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Inst. Tech., Centerton, N.J.

TREWARTHA, G.T., 1954: *An Introduction to Climate.* Third Edition. New York, McGraw-Hill. 402 pp.

TREWARTHA, G.T., 1968: *An Introduction to Climate.* Fourth Edition. New York, McGraw-Hill. 408 pp.

WATTS, F.B., 1968: Climate vegetation, soil. Pages 78-111 *in* Warkentin, J. (Ed.). *Canada, a geographical interpretation.* Toronto, Methuen. 608 pp.

WEIR, T.R. (Ed.)., 1960: *Economic Atlas of Manitoba.* Manit. Dep. Ind. Commerce. 81 pp.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM and G.D. ADAMS, 1975: Developing a wetland classification for Canada. Pages 497-511 *in* Bernier, B. and C.H. Winget (Eds.). *Forest soils and forest land management.* Proc. 4th North Am. For. Soils Conf., Laval University, Quebec, August 1973. Quebec, Les Presses de l'Université Laval.

ZOLTAI, S.C., J.P. SENYK, P. GIMBARZEVSKY and A. KABZEMS, 1967: Land capability classification for forestry; Manitoba and Saskatchewan. Pages 22-30, *Can. Land Inventory,* Rep. No. 4. 2nd Ed. Can. Dep. Reg. Econ. Expans.

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