A SUMMER CLIMATE CLASSIFICATION FOR THE FORESTED AREA OF THE PRAIRIE PROVINCES USING FACTOR ANALYSIS

BY

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ABSTRACT

A variety of climatic classifications is available for the Prairie Provinces, or portions thereof, based on modifications of Köppen's or Thornthwaite's systems or other criteria. Such classifications, often based on predetermined *a priori* class limits, lack the detail required for assessing forest land-use productivity or conducting and applying forest research; generally, they show few subdivisions of the forested areas. A climatic classification using a factorial *a posteriori* approach was developed for the forested areas of the Prairies based on daily temperature and precipitation records from 303 stations for the months May to September for the years 1961 to 1970. 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°C in the months May to September, and water deficiency values for the months June to September. Only 16 of these were later shown to be statistically significant, accounting for 89.5% of the variance. The input data for the relevant variables were used to obtain an intercorrelation matrix for a factor analysis. Roots (eigenvalues) and vectors (eigenvectors) were then extracted from the matrix, and factor scores for each station were developed. The factor scores for each station were used for a hierarchical profile grouping procedure to delineate groups of stations having similar summer climatic regimes. Discriminant analysis was used as a test of the factor analysis and hierarchical grouping procedures. It was also used to establish the degree of stability within and between groups and to position the boundaries between groups. A map classifying the summer climate of the forested and adjacent areas of the Prairie Provinces was produced with climatic zones derived from 26 groups of climatological stations.

RESUME

Il existe une variété de classifications climatiques fondées sur les systèmes de Köpen ou Thornthwaite ou autres critères, pour les provinces des Prairies ou parties de celles-ci. Avec ces classifications, souvent fondées sur des limites de classes *a priori* prédéterminées, on ne peut évaluer la productivité des terres forestières, ou diriger et appliquer des recherches forestières; habituellement, elles subdivisent peu les secteurs forestiers. Les auteurs ont mis au point une classification climatique en employant une approche factorielle *a posteriori* pour les zones forestières des Prairies, fondée sur la température quotidienne et les précipitations enregistrées dans 303 stations, de mai à septembre des années 1961 à 1970. Une matrice de 22 variables indépendantes expliquant la plupart des variations entre les stations fut utilisée. Les variables employées étaient l'élévation, la longitude, la latitude, les températures moyennes des mois de mai à septembre, les précipitations totales pour les mêmes mois, la fréquence de jours à température minimum >-2.2°C pour mai à septembre et les déficiences en eau pour les mois de juin à septembre. Seulement 16 de celles-ci s'avérèrent par la suite significatives, statistiquement, tenant compte de 89.5% de la variance. Les données d'intrant pour les variables pertinentes furent utilisées pour l'obtention d'une matrice d'intercorrélation pour analyse d'un facteur. Des racines (valeurs propres) et des vecteurs (vecteurs propres) furent ensuite extraits de la matrice, et des comptes (scores) factoriels pour chaque station furent mis au point. Les comptes factoriels de chaque station furent utilisés pour établir une méthode groupant des profils hiérarchiques afin de tracer des groupes de stations dont les régimes climatiques d'été étaient similaires. Une analyse discriminante servit aux tests d'analyse factorielle et de méthodes de groupage hiérarchique. Elle fut aussi employée pour éstablir le degrée de stabilité au sein des groupes et inter-groupes, puis pour situer les limites des groupes. Une carte classifiant le climat estival des secteurs forestiers et ceux y adjacents des provinces des Prairies fut produite avec zones climatiques dérivées de 26 groupes de stations climatologiques.

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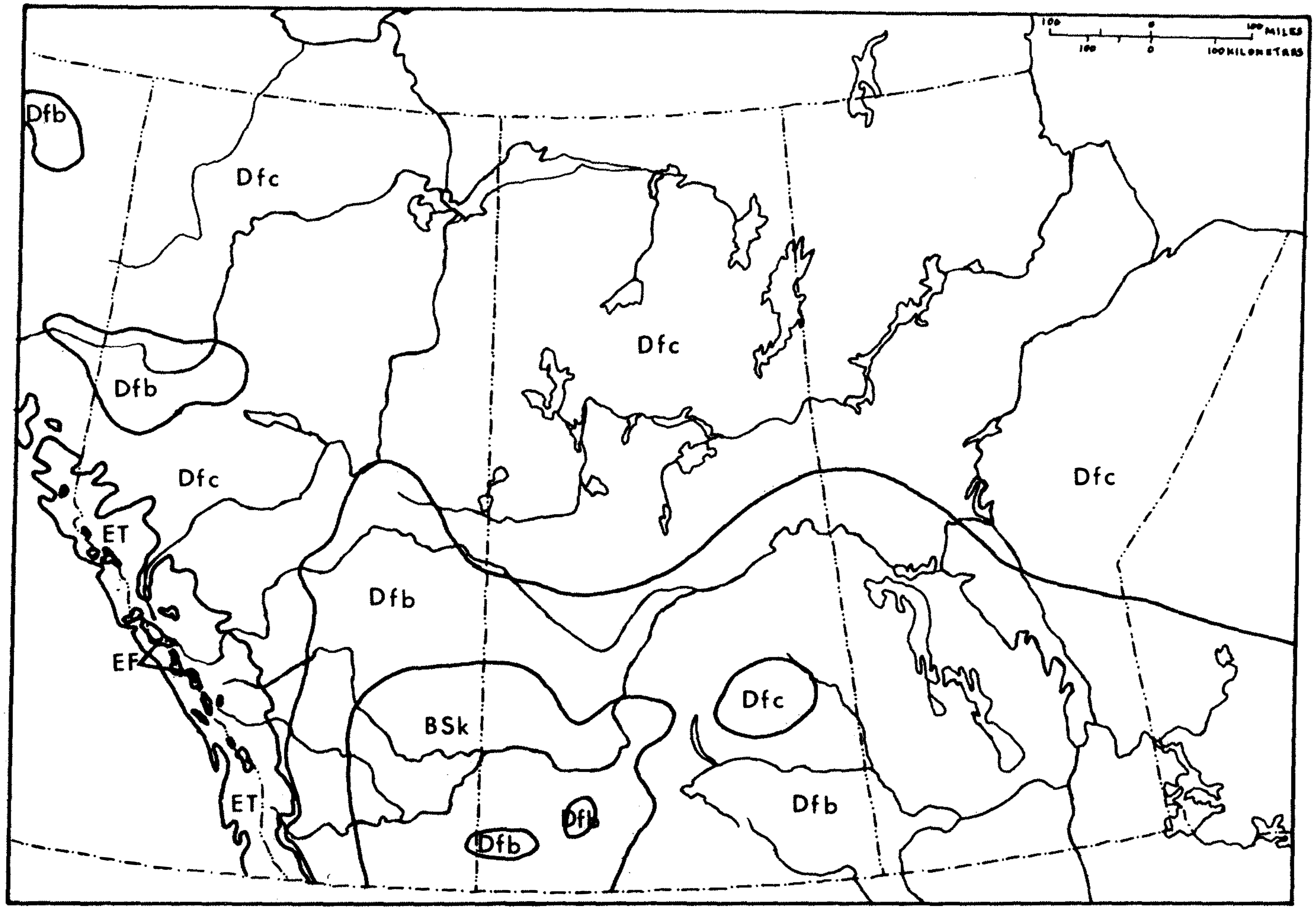
INTRODUCTION

An understanding of climatic data and patterns of climate is essential to the maintenance of proper resource development and land productivity in any region. The need for the application of climatic classification for forest management and research has been recognized at both the national and regional levels (Powell 1970). In the Canadian Forestry Service, Western and Northern Region, climatic classification is especially needed for stand establishment studies, tree improvement and breeding trials, site and productivity classifications, delineating hazard areas for disease and insect organisms, and fire protection. A forest climate classification would have been useful for the forest land classification under the Canada Land Inventory Program, and can serve as background information for a number of federal and provincial departments undertaking resource or socioeconomic studies in the forested areas of the provinces of Alberta, Manitoba, and Saskatchewan.

Several climatic classifications are available for the Prairie Provinces, or portions thereof, based on the Köppen (1918, 1923, 1931, 1936) or Thornthwaite (1931, 1948) systems or modifications of them (Government of Alberta and University of Alberta 1969; Longley 1970; Rheumer 1953; Richards and Fung 1969; Sanderson 1948; Trewartha 1954, 1968; Weir 1960). Figure 1 shows the Prairie Provinces using Köppen's classification based on data for the 1921-1950 period (Canada Department of Mines and Technical Surveys 1957, Plate 30). Several detailed classifications 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, or their discipline-oriented classifications are not suitable for extension into the forested areas. Further details on the climate or climate-related classifications available for the Prairie Provinces are given by Powell (in press). Many of these climatic or discipline-oriented classifications were based on predetermined, often arbitrary, climatic parameter class limits or included subjective biases about vegetation distribution or physiographic features. Generally, they were also based on data from only a few long-term stations, often situated in urban environments or in major river valleys that are not necessarily representative of the forested area. They are therefore inadequate for assessing forest land use productivity or use in forestry management and research.



BSk = Middle Latitude Steppe; Dfb = Humid Continental, Cool Summer, No Dry Season;
Dfc = Sub Arctic; ET= Tundra, EF = Ice Cap.

Fig. 1. Climatic regions based on Köppen's classification and data for the 1921-1950 period (Source: Canada Department Mines and Technical Surveys 1957)

This lack prompted a preliminary study of a portion of Alberta in 1969 to select a suitable methodology for classification in a forested area. The primary stratagem in this study was utilization of an analytic system that allows the data to select the classification criteria, thereby avoiding the inherent limitations of the classical or traditional *a priori* climatic classifications of Köppen, Thornthwaite, and their followers. Important tactical considerations included using as many climatological stations as possible and stressing climatic parameters rather than vegetation or physiography. A factor analytic approach was selected, using a 15-year data period for 54 stations and employing 75 variables (MacIver 1970; MacIver *et al.* 1972). Climate is a multivariate phenomenon; the application of factor analysis to climatic classification therefore seemed appropriate because it allows for the identification of the basic underlying patterns that control "regionalization" and indicates the most important variables within a complex set of multivariate data. Factor analysis, followed by an appropriate grouping procedure, is a very flexible methodology that lends itself to numerous uses because the individual user is presented with a series of station linkages for either detailed delineation or generalized mapping. The methodology for using factor analysis for regionalization has been presented by King (1969).

FACTOR ANALYSIS

The general goal of factor analysis is the reduction of a set of variables to a smaller set of new, uncorrelated variables that are defined solely in terms of the original dimensions and that retain the most "important" information contained in the original data. The factor analytic approach therefore provides a rational statistical procedure for analyzing climatic data to identify the important variables. The first step in the analysis is to obtain an intercorrelation matrix for the input variables. The second major step is extraction of eigenroots (eigenvalues) and vectors (eigenvectors or factor loadings) from the intercorrelation matrix. Eigenvalues and the associated eigenvectors are a measure of the relative importance of their respective components (variables). Factor analysis therefore exploits intercorrelation between the input variables to reduce the original matrix to a matrix of independent factors. A factor is then a linear function of the input variables with the absolute magnitude of the coefficient for each variable (factor loadings) indicating its importance for that factor. One or more variables having specified high values for their factor loadings can then be identified as the significant determining variables for each factor. The analysis therefore provides a measure of the discriminating power (eigenvalue) and percentage of total variation accounted for by each factor. The first factor has the highest eigenvalue and percentage of the total explained variation. Each successive factor is less important by these two criteria, and all are mutually independent, or orthogonal. Only factors with a certain eigenvalue and accounting for a certain percentage of the total variation are generally used for characterization. The useful output of factor analysis at this stage comprises a series of significant factors with the signed loadings of their determining input variables, together with the eigenvalues and the variation accounted for by each factor. The next step in the factor analytic procedure is derivation of indices or profiles in the form of factor scores for each station. A factor score is the sum of the products of the factor loadings and normalized input data for one factor and station. A factor score is derived for each significant factor for every station. A grouping or cluster analysis procedure is then applied to the factor scores to group the individual stations. The boundaries of such groupings can be located where the most marked changes occur in the significant climatic variables.

Steiner (1965) was the first to use the factor analytic approach for climate. Factor analysis was also used by Miller and Auclair (1974) to show a relationship between Canadian forest regions and climate characterized by annual mean temperature and precipitation and July average daily maximum temperature. McBoyle (1971, 1972) has used a similar approach based on principal component analysis for climatic classifications of Australia and Europe. Also employing principal component analysis, Nicholson and Bryant (1972) showed that regional climatic classification and an understanding of the differences among regions was an extremely useful method in assessing forestry planting and other problems in Newfoundland. Factor analysis and principal component analysis have much in common and are often referred to as identical, but have important mathematical and conceptual differences between them (King 1969). In factor analysis, the diagonal elements of the correlation matrix (R) are replaced with values other than unity, which distinguishes it from principal component analysis. Factor analysis usually implies some hypothesis as to the number of common factors underlying the set of study variables. The variance of every variable then is seen as involving some common variance accounted for by these factors.

STUDY OBJECTIVE

In the present study, the factor analysis approach is used to establish summer climatic zones defined by homogeneous groups of climate stations in the area that comprises the contiguous forested portions of Alberta, Saskatchewan, and Manitoba and the adjacent parkland-grasslands. Forested outliers such as the Cypress Hills in southeastern Alberta and southwestern Saskatchewan were not included. A few climatological stations in the adjacent portions of British Columbia, Ontario, and the Northwest Territories were included to aid in the placement of climatic boundaries. The study was restricted to the summer months, May to September. As data are available from the majority of the forest-fire weather stations only for those months, a full-year study would have a greatly reduced density of stations for analysis, especially in Alberta. The authors judged that a classification based on summer data would have greater utility to forestry than a full-year classification based on an inadequate network of stations.

The object of the present report is to present the methodology of this approach to climatic classification and to provide a map of the macroclimatic groupings of stations for the forested areas of the Prairie Provinces. This study uses the same factor analytic approach employed for the preliminary study (MacIver 1970; MacIver *et al.* 1972), but incorporates a number of improved features: a shorter, 10-year period; a larger network of stations (and denser for central Alberta); 22 largely independent input variables rather then 75, many of which showed a high dependence on other variables; a hierarchical grouping procedure rather than an algorithmic; discriminant analysis to test whether the groups were significantly different; and boundaries of the climatic groupings positioned through the use of the most statistically significant variables rather than the mean distance between the closest two stations of adjacent climatic groups. Earlier phases of this study have been briefly reported in conference publications (Powell and MacIver 1975 a, b, c), and results for the Hinton-Edson area of west-central Alberta were reported separately (Powell and MacIver 1976).

STUDY AREA

The study area, the forested and agricultural fringe area of the Prairie Provinces, slopes northeastward from approximately 3000 m in the Rocky Mountains to about 200 m north of Lake Athabasca and to near sea level in the Hudson Bay Lowland Region (Fig. 2). Four major physiographic regions occur within the study area (Canada Department of Energy, Mines and Resources 1973, Plate 5-6). The Cordilleran Region, represented by the Rocky Mountains and Foothills, forms a zone 65-160 km wide that follows the Alberta-British Columbia boundary from 49° to 55° N latitude. The Interior Plains Region lies east of the Rockies and is actually composed of three plains at elevations of approximately 230, 490, and 760 m, each with numerous local topographic variations. The Manitoba Escarpment separates the Manitoba Plain from the Saskatchewan Plain, while the Missouri Escarpment separates the latter from the Alberta Plain and Plateau. Within northern Alberta, the plateaus form several prominent upland areas separated by lowlands. The Canadian Shield, situated generally east and north of the Interior Plains, covers over half of Manitoba, much of northern Saskatchewan, and the extreme northeastern portion of Alberta. Its western boundary runs from southeastern Manitoba around the eastern side of Lake Winnipeg to the Slave River in northeastern Alberta near the northern boundary of the study area. Although the climate is continental, local weather can be affected by bodies of water in the region. The Canadian Shield is covered with numerous lakes; some large lakes are also found in the Interior Plains. The Hudson Bay Lowland Region forms a band up to 190 km wide in northeastern Manitoba adjacent to the Hudson Bay coastline, with numerous bogs and shallow lakes.

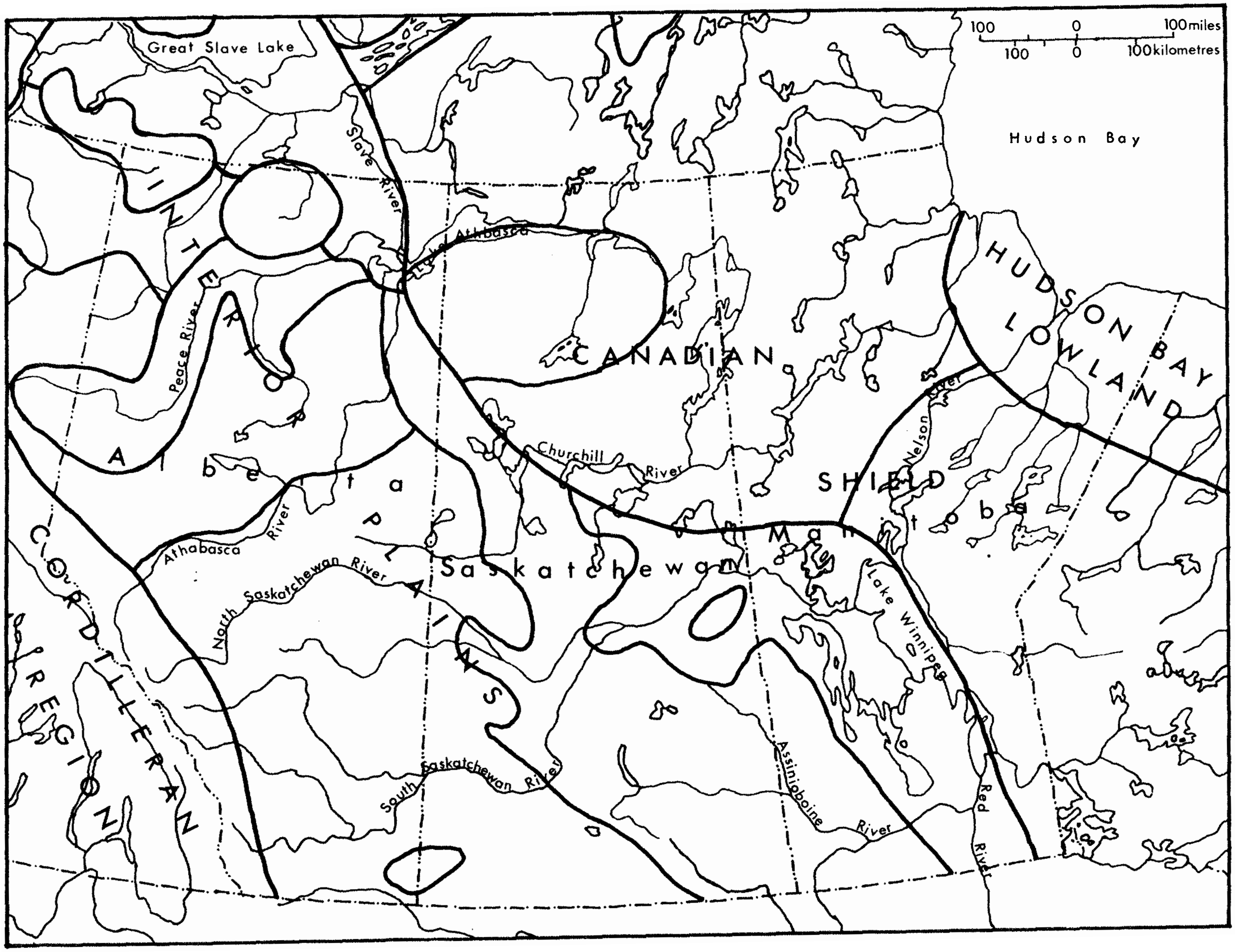


Fig. 2. Physiographic regions of the Prairie Provinces (after Canada Department of Energy, Mines & Resources 1973).

The dominant soil groups of the Interior Plains Region are chernozemic, solonetzic, or luvisolic (Canada Department of Energy, Mines and Resources 1973, Plate 41-42). The black and dark gray chernozemic soils occur largely in the parkland areas. Eutric brunisols occur in the northern Peace River area, and cumulic regosols at the east end of Lake Athabasca. The main soils of the Canadian Shield in Saskatchewan and northwest Manitoba are humo-ferric podzols. Gray luvisols occur throughout much of the northern Interior Plains Region and on the Shield south of the Hudson Bay Lowlands. Large areas of gleysols occur in northern Alberta. A zone of continuous permafrost occurs in northeast Manitoba, and a zone of intermittent permafrost through northeast Saskatchewan and northern Manitoba (Brown 1967; Zoltai 1971; Zoltai and Tarnocai 1969), extending as far south as Lake Winnipeg in Manitoba.

The climate of the study area is subhumid continental with long, cold winters and short, cool summers. The Köppen system classifies the whole area, except the Rocky Mountains, as a Sub-Arctic or cold "snowy forest" climate (D), with the area subdivided on the basis of whether there are four or more months with mean temperatures of 10°C or above (Db) or less (Dc) (Fig. 1). Longley (1972) showed that the boundary between the Db and Dc climates has a frost-free period of approximately 90 days and the number of growing degree-days above 5.6°C is in general in the 1055-1167 range. A portion of the Cordilleran region lies within Köppen's Arctic or Polar E-type climate zones in which the mean temperature of the warmest month is below 10°C. Mean annual temperatures in the study area range from -1.7° to 5.0°C, and annual precipitation from about 300 to >1000 mm, with a large percentage occurring during the summer months.

Approximately three-quarters of the geographical area of the Prairie Provinces is forested (Fig. 3). Most of the forested area consists of the boreal forest, which is characterized as mainly coniferous (white and black spruce, balsam fir, jack and lodgepole pine) with some broadleaf trees such as trembling aspen, balsam poplar, and white birch (Rowe 1972). Between the mixed conifer and hardwood forest of the Boreal Region and the grassland lying south of the main study area is a zone dominated by aspen, often referred to as the Aspen

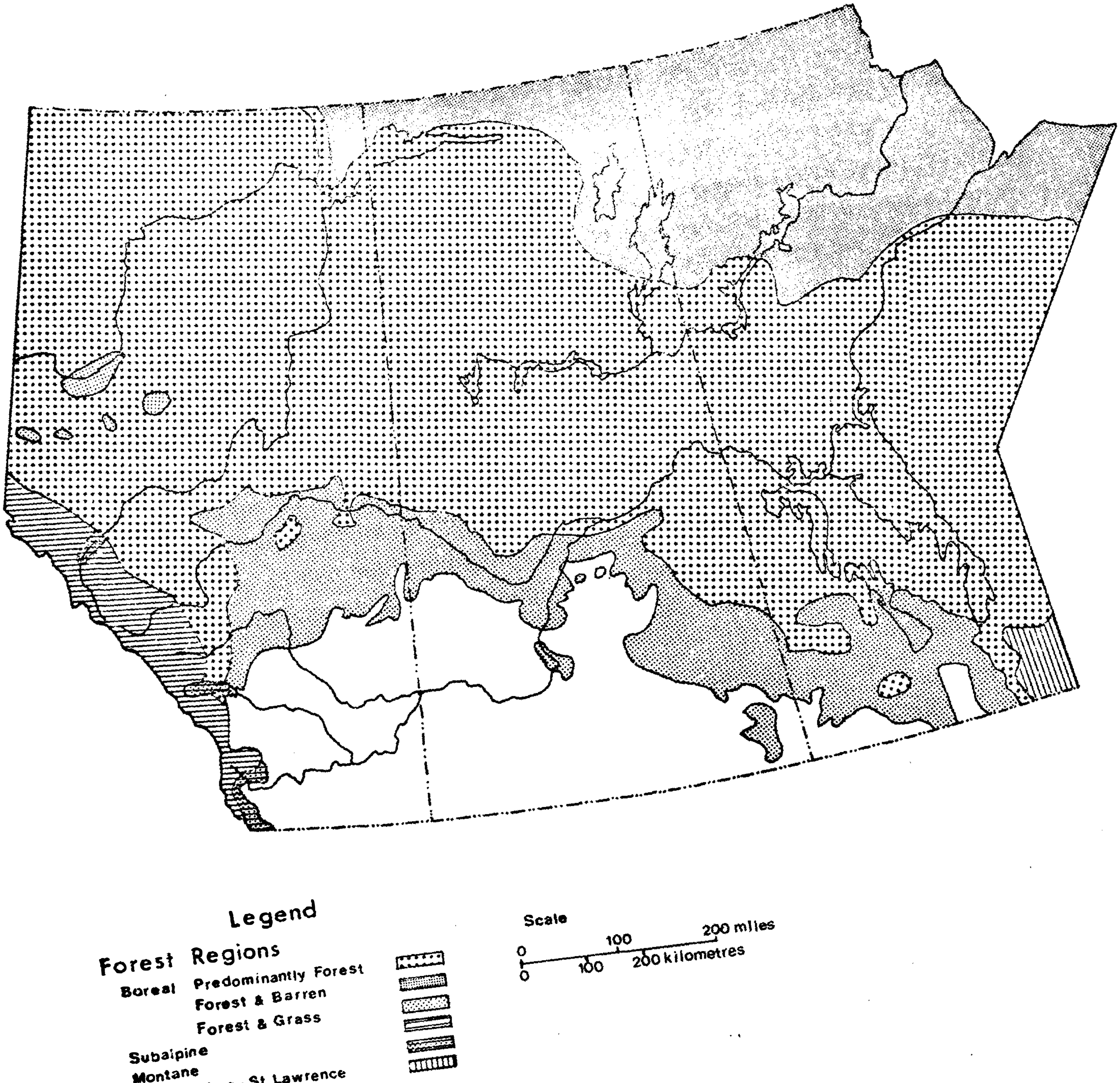


Fig. 3. Forest regions of the Prairie Provinces (after Rowe 1972).

Parkland (Bird 1961). Zoltai (1975) recognized a Parkland-Boreal Forest Transition Zone between the Boreal Forest and Aspen Parkland. Outliers of the Aspen Parkland zone occur in the Peace River-Smoky River-Lesser Slave Lake area within the boreal forest, and within the grassland zone especially of Saskatchewan and Manitoba. In southeastern Manitoba the boreal species mix with species characteristic of the Great Lakes-St. Lawrence Forest Region. The Subalpine Forest Region, comprising much of the southwestern Alberta border area, is a mixed coniferous forest of Engelmann spruce, alpine fir, and lodgepole pine. The Montane forest (characterized primarily by lodgepole pine, Douglas-fir, white spruce, aspen, and grasslands) is located in the extreme southwest of Alberta and in the major river valleys east of Banff and Jasper. In northern Manitoba and Saskatchewan and northeastern Alberta, an open woodland region occurs, which in extreme northern Manitoba gives way to a tundra-open woodland (Canada Department of Energy, Mines and Resources, 1973, Plate 45-46).

METHODS AND MATERIALS

The stages in the analysis are outlined in a schematic flow diagram in Fig. 4. Details for each stage are given below.

DATA PERIOD

Many forestry stations have only recently been established and take only summer forest fire weather data. In order, therefore, to use many of these stations in the analysis, it was necessary to consider a short data period and a classification involving only the summer months.

Most climatic classifications are based on the longest possible data period or a 30-year period for establishing standard climatological normals. Landsberg and Jacobs (1951) suggest differing periods for stable frequency distributuions for temperature and precipitation in mountainous and level terrain. Court (1968), however, has shown that a 10- to 15-year period gives reliable results for most climatic parameters in most areas. Because many stations on the prairies, especially forestry ones, have only short-term records, tests were run to determine the minimum data period required to attain the degree of stability inherent in 30-year

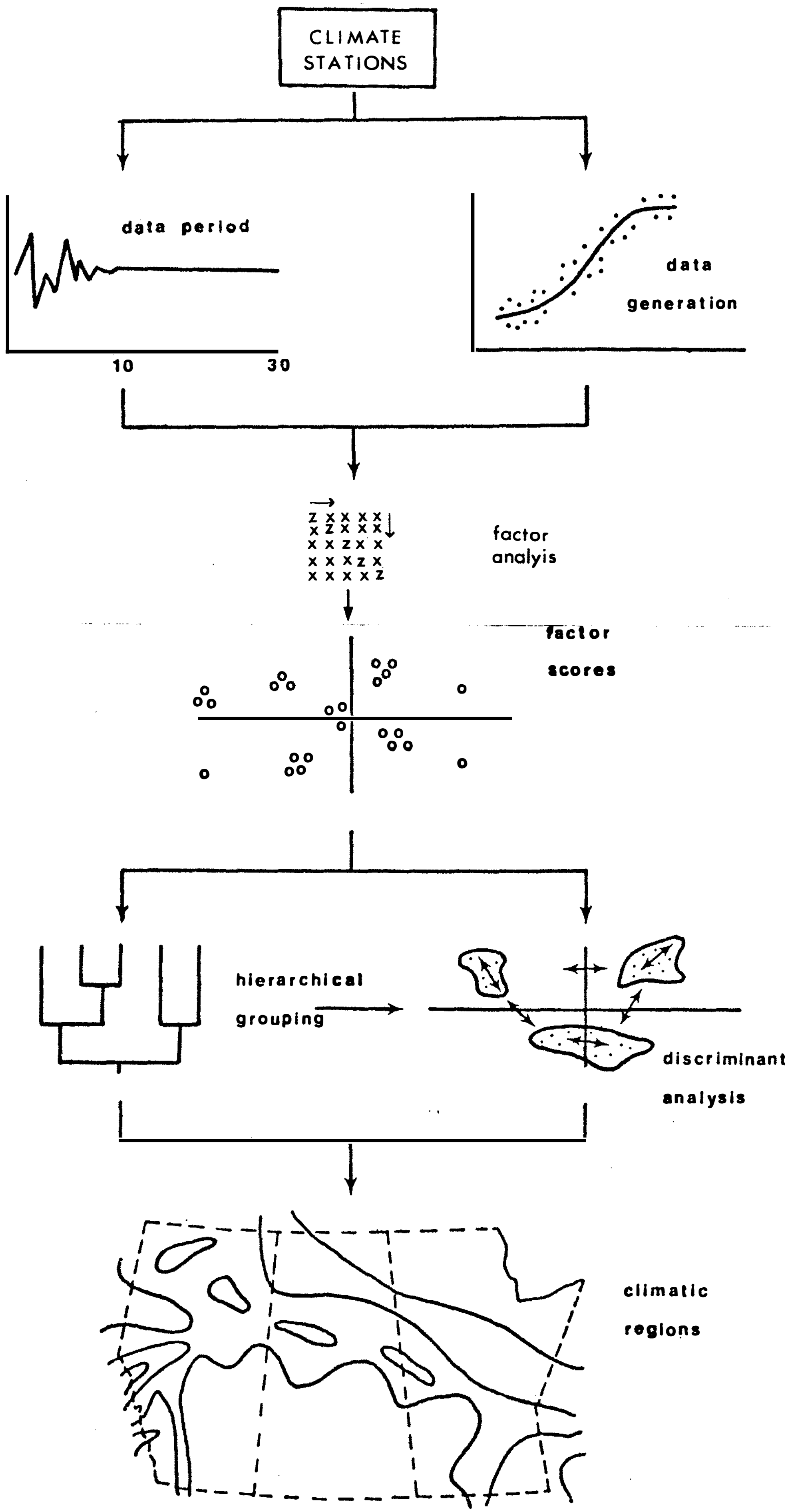


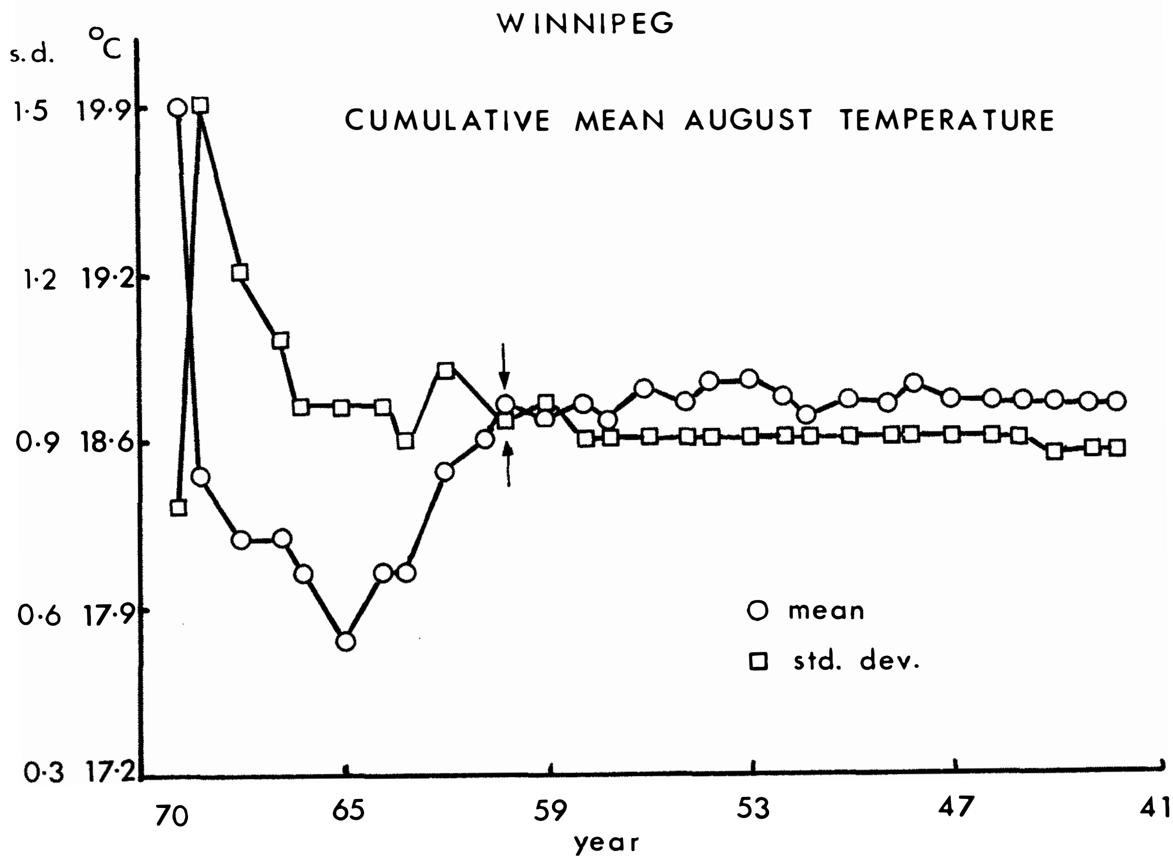
Fig. 4. Schematic flow diagram of analytical procedures

normals. Four long-term climatic stations, Calgary, Edmonton, Saskatoon, and Winnipeg, were chosen to serve as representative test stations. The cumulative means for temperature and precipitation were calculated for each of the months May to September, and their standard deviations were calculated over the period 1941-70, beginning with 1970. Figure 5 shows the cumulative mean temperature and cumulative totals of precipitation in August for Winnipeg. The minimum data period required is indicated when the accumulated mean does not differ significantly from the 30-year mean value and when the standard deviation about the mean is at a minimum. The analysis showed that a data period of 10 years or less (see arrows of Fig. 5) for both temperature and precipitation for the tested stations satisfies these conditions. The period 1961-1970 was therefore selected as the period having the greatest density of stations at the time the study was started in 1971.

SELECTION OF STATIONS

All climatological stations in the predominantly forested area and fringe agricultural areas with 6 or more years of daily temperature and precipitation data during the months May to September inclusive in the 1961-1970 period were considered for use in this study. A few stations with only 4 or 5 years of record were included to try to fill large geographical gaps, especially in the data-sparse areas of Saskatchewan and Manitoba. A total of 323 locations was selected, 194 in Alberta, 59 in Saskatchewan, 62 in Manitoba, and 8 outside the Prairie Provinces (Fig.6). At three locations, data from 2 or in one case, 3 stations were combined to provide one set of data for a location. At 3 other locations, the name of the station was changed during the period but the site was unchanged. Daily climatological data were obtained on magnetic tape from the Atmospheric Environment Service, Environment Canada for each station for the period 1961 to 1970 and for the months April to October inclusive, except that the 1970 data from the Alberta forestry stations were obtained separately on tape from the Alberta Forest Service.

Figure 6 shows that the distribution of available stations was not uniform throughout the study area. Coverage in Alberta was fairly good, except in the extreme north. Stations in Wood Buffalo National



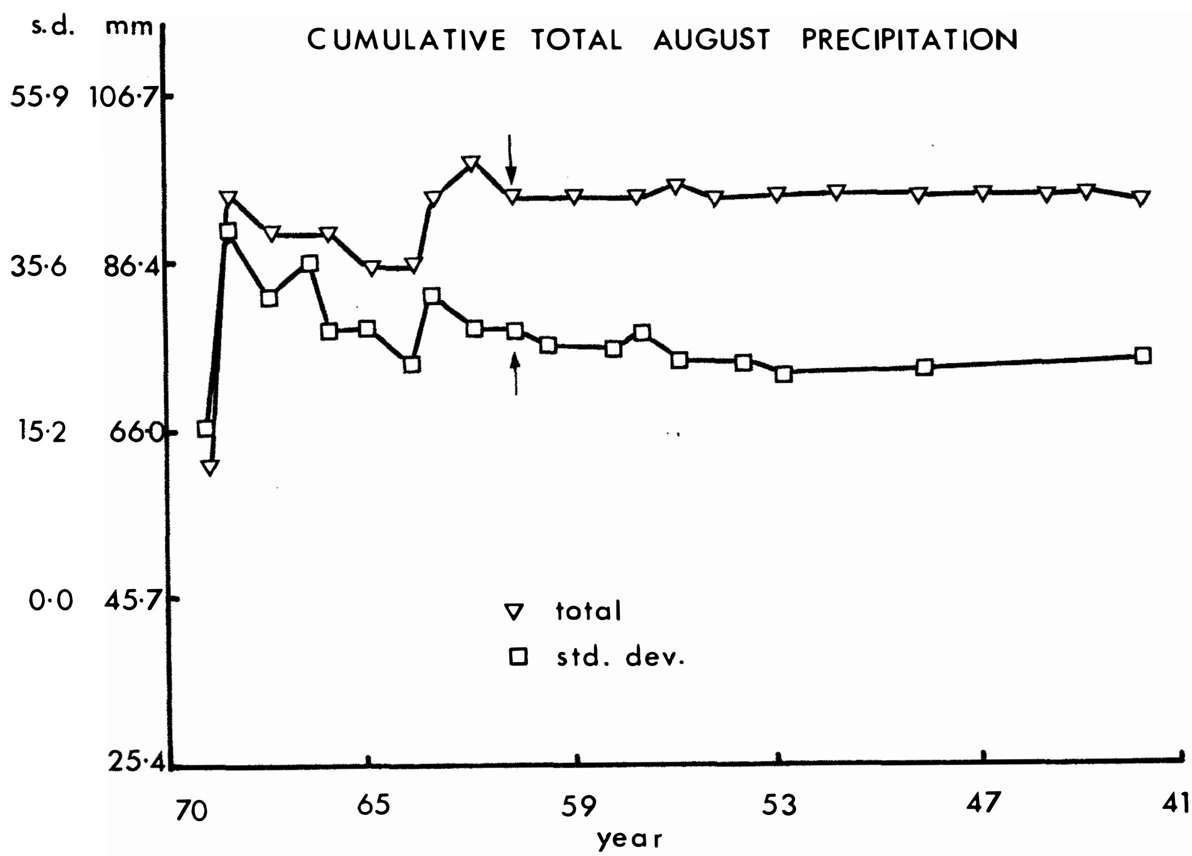


Fig. 5. Cumulative mean temperature and precipitation in August for Winnipeg

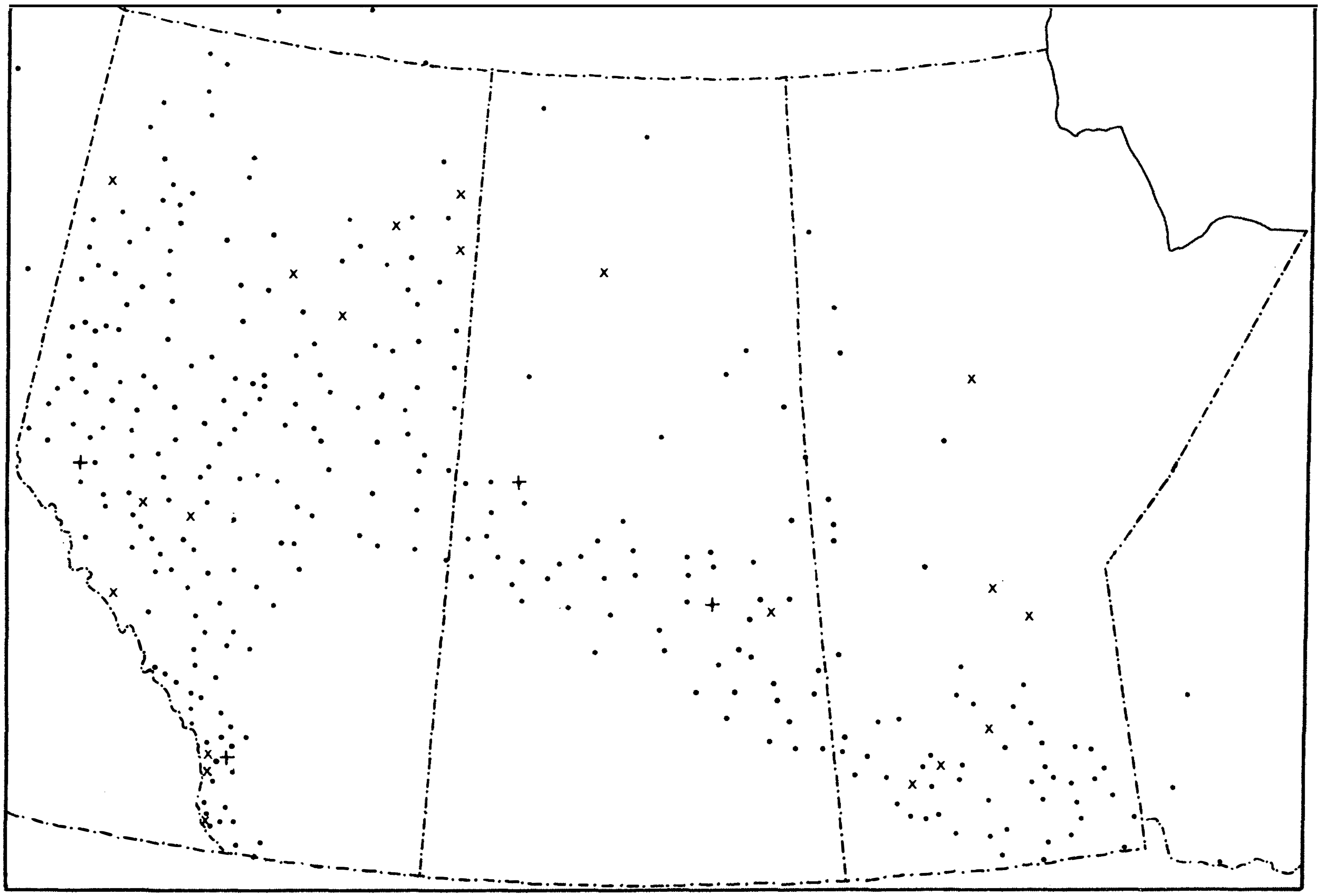


Fig. 6. Location of the 323 selected stations. Those stations eliminated for the factor analysis are indicated by a cross (X) and those dropped after the grouping by a plus (+).

Park have been in regular summer operation only since 1968, and several other Alberta Forest Service lookout stations were not opened, or did not record both temperature and precipitation, until the second half of the study period. In Alberta there is also a paucity of stations in Banff and Jasper national parks, especially at the higher elevations. In Manitoba and Saskatchewan there are very few stations in the boreal forest north of the agricultural fringe. A few of recent origin (1966 onwards) were included, but were later eliminated from the factorial analysis. Most fire weather stations in Manitoba and Saskatchewan have recorded only precipitation, and irregularly. Many of the stations in northern Saskatchewan and Manitoba are located on lakes or waterways and probably do not provide a reliable indication of the climate away from the lakes (Longley 1972). Similarly, data from stations located in valleys or at lookout stations on the tops of hills elsewhere in the study area may be unrepresentative of the surrounding forested area. They are, however, the only stations available and were consequently accepted.

DATA BASE AND GENERATION OF MISSING VALUES

The statistical analysis for the macroclimate grouping requires complete sets of daily observations for each station for the period 1961-70 from May to September inclusive. Stations with missing data can therefore be included only if suitable estimates can be generated for the missing values. It was necessary to generate estimates for many of the forest-fire weather stations, especially for portions of May and September when they are often closed. The estimation procedure began by curvilinear regression analysis using available data from an incomplete station as the dependent variable, with corresponding data from a nearby complete station as the independent variable. Using the analysis of variance test, if the F-ratio was significant at the 95% confidence level, the curvilinear regression equation derived from the analysis was used to estimate values for the missing data from the corresponding data from the complete station. Third-order polynomial regression equations were used to generate missing values for temperature, precipitation, and frequency of days with a minimum temperature $>-2.2^{\circ}C$.

Of the 115 stations for which curvilinear regression and subsequent analysis of variance tests were applied, the regressions for 20 stations were not significant at the 95% confidence level; those stations were eliminated from further analysis. The majority of the eliminated stations were rejected on the basis of poor precipitation prediction, partly due to the discontinuous nature of convective summer precipitation.

The data base for the multivariate technique of factor analysis therefore consisted of the complete daily data or estimated values for the period 1961-1970 from May to September for 303 climatological stations (Fig. 6).

VARIABLES

Temperature and precipitation, the variables utilized in most classification models to represent and define the climate of a region, were used along with two additional climatic variables: frequency of days with a daily minimum temperature >-2.2°C and water deficiency. These additional variables represent limiting climatic factors, which when combined with other climatic variables, allow for a greater degree of regional discrimination of climatic variation. The -2.2°C (28°F) minimum temperature was chosen as a limiting factor because values below it are considered to be killing frosts for most sensitive vegetation. Water deficiency values were calculated using Thornthwaite's Water Balance technique (Thornthwaite and Mather 1955) adjusted for a 7-month period from April to October, assuming a soil moisture storage level of 100 mm (4-in. equivalent) per year by the end of March. The three location variables of elevation, latitude, and longitude were also used in the analysis; these provide an indirect correlation to radiation received at the earth's surface.

The input variables used in the present analysis, with their assigned number, are listed in Table 1. May water deficiency was originally considered as a variable (Powell and MacIver 1975b), but was not used as input for this study because values were zero at all stations, except for the added station of Emo, Ontario.

Table 1. List of the 22 climatic input variables used in the analysis

Variable No.	Description	Variable No.	Description
1	Elevation	12	Total Precipitation-Aug.
2	Latitude	13	" " -Sept.
3	Longitude	14	Freq. of days>-2.2°C-May
4	Mean Daily Temperature-May	15	" " -June
5	" " " -June	16	" " -July
6	" " " -July	17	" " -Aug.
7	" " " -Aug.	18	" " -Sept.
8	" " " -Sept.	19	Water Deficiency -June
9	Total Precipitation -May	20	" " -July
10	" " -June	21	" " -Aug.
11	" " -July	22	" " -Sept.

FACTOR ANALYSIS

An R-mode factor analysis of the input data matrix was employed. Factors were retained if they had eigenvalues greater than unity and accounted for >5% of the total variance (King 1969). A normal varimax rotation was carried out on the factor solution (Harman 1967). This routine employs a series of orthogonal transformations of pairs of factors to simplify the columns of the factor loadings matrix. The communality (coefficients when computed as proportions) will be a maximum of 1.00 (100%) only when all the variance of a particular variable is completely accounted for by the extracted factors. The varimax rotation yields a number of orthogonally independent factors with only those factor loadings having an absolute numeric value ≥0.700 considered significant. The coefficients generated in this rotation in combination with the 22 input variables per station were used to derive weighted station indices in the form of factor scores.

HIERARCHICAL GROUPING PROGRAM

The independent normalized factor scores generated in the factor analysis are used as input for the Hierarchical Grouping procedure (Veldman 1967), which compares each station's factor scores and progressively groups the stations in a sequence that minimizes the increment of within-group factor-score variation at each step. The factor scores are used rather than original variables to ensure independence in the input matrix. The method begins by defining each station as a group. The analytic procedure then groups stations by a series of stepwise decisions that reduce the number of separate entities by one in a sequence that minimizes the increment of within-group variation or error at each step in the process, until all stations are in one group. The output for every step consists of the station or stations in each group and the aggregate within-group error. This output indicates the optimum grouping sequence, and the cost, in terms of increasing within-group error, for each successive decrement in number of groups. It does not indicate a "correct" solution in terms of number of groups. That decision can be reached in a number of ways, depending on nature of the classification requirement.

A plot of aggregate error over number of groups was made to identify points in the grouping process where the relationship between number of groups and aggregate error appeared relatively favorable. The inflection points on the graph indicate favorable grouping levels, because these are the points where the largest error increase occurs between adjacent groups in the sequence.

As the grouping procedure provides no statistical basis for inferring the stability of the groups, it is necessary to carry out discriminant analysis or analyses of variance to check the characteristics of generated groups; the former was employed for this study.

DISCRIMINANT ANALYSIS

The use of multiple discriminant analysis is essential to the climatic classification model since it provides the only significance test of both the factor analysis and hierarchical grouping procedures.

It also identifies the major discriminating variables. Multiple discriminant analysis requires fulfillment or satisfaction of two assumptions: 1) that the variables are normally distributed, and 2) that the groups have a common variance-covariance matrix. In order to satisfy both of these assumptions, the outputs from the factor analysis (factor scores per station) were used as input to the multiple discriminant analysis technique. The normalized eigenvectors were used as the coefficients of the discriminant functions. This technique derives a set of linear discriminant functions that maximize the between-group differences (King 1970). The relative weightings on each linear discriminant function can then be used to determine which variable or variables separate one climatic group from another. It is also logical to use these same statistically important variables as an aid in delimiting climatic boundaries between groups.

Discriminant analysis tests the null hypothesis that the groupings of stations determined by the hierarchical grouping program are not separate and exclusive, through the Wilk's Lambda criterion (Mather 1969). It can also be employed to test the "rule of thumb" used in the factor analysis procedure of a cutoff limit of 1.00 for the eigenvalues to denote the significant factors.

CLIMATIC MAP

A map was drawn of the macroclimatic groupings of stations, using the statistically significant variables between the climatic groups to aid in the placement of the boundaries. The range, mean, variance, and standard deviation of each variable in each group were used to discriminate between adjacent climatic zones. The range and mean values of every pair of adjacent climatic zones were inspected to detect the variables that appeared to be most important in delimiting the zones. Those variables were then tested for statistical significance of differences using Student's t-test at the 95% confidence level. Since the significant variables relating to the boundary between any two climatic zones may be different for each pair of zones, the statistical test was used between each pair of adjacent zones. When more than one variable was important in delimiting the boundary between two climatic zones, the combined influence of the significant variables was used to derive boundary placement.

Where plausible, spatially separate portions of the same climatic zone were joined. A few stations disjunctly located from their zones and considered to represent local climates or variations were included in the dominant surrounding zone.

RESULTS

The factors, eigenvalues, communalities, and rotated factor loadings for the cascaded matrix of the 10 rotated factors of the factor analysis are shown in Table 2. The analysis indicated that there were nine factors, each of which explained at least 5% of the total explained variance of the 22 input variables and had an eigenvalue >1.00 (Table 2). The tenth factor failed to meet either criterion and was eliminated. Table 3 gives the factors and their associated input variables, together with the percentage of the total variance accounted for by each factor. The first three factors explain 48% of the variance, and the nine significant factors 89.5% of the variance. These nine factors incorporate 16 of the original 22 input variables, and were therefore the significant factors for scoring and grouping of climatological stations. Factor 1, accounting for 18.7% of the total variance, represents spring and early summer temperatures. Factor 2, which explains 16.3% of the total variance, is composed of positive loadings for July temperatures and negative loadings for longitude and elevation. Factor 3, accounting for 13.0% of the total variance, relates to summer precipitation and August water deficiency. Each of the other factors explained <10% of the total variance.

The hierarchical program to group the 303 stations into climatic groups indicated 15 or 26 as the relatively favorable numbers of groups (Fig. 7). The selected grouping was 26 groups, because this meant a lower accumulated within-group variation or error in the grouping routine. If 15 groups had been selected, which is the next major slope discontinuity on the curve, the accumulated within-group error would be more than 50% higher than with 26 groups. A larger number of groups with less accumulated within-group error could have been selected, but this would have increased the problem of grouping stations for management purposes. Appendix A gives a complete listing of stations for the 26 climatic groupings. Four stations were dropped from the groupings (Dorintosh, Muskeg R.S., Tisdale, and Willow

Table 2. Cascaded matrix of rotated factors with eigenvalues, communalities, factor loading, and percentage of total explained variance

Factor Number		1	2	3	4	5	6	7	8	9	10
Eigenvalue		4.114	3.597	2.853	2.125	1.618	1.487	1.353	1.338	1.162	0.675
% of Total Variance		18.7	16.3	13.0	9.7	7.4	6.8	6.2	6.1	5.3	3.1
Variable No.	Communality over 10 factors					Factor loadings					
14	0.931	-0.928	0.133	-0.011	-0.011	-0.101	0.078	-0.077	0.166	0.007	0.039
4	0.922	-0.825	0.329	0.067	-0.058	-0.256	0.193	0.079	0.054	0.019	-0.120
15	0.879	-0.763	0.066	0.022	0.058	0.170	0.001	-0.416	0.195	-0.196	0.095
18	0.951	-0.697	0.331	0.063	-0.011	-0.029	-0.075	-0.200	0.188	-0.077	0.514
5	0.952	-0.642	0.638	0.095	-0.074	-0.253	0.146	-0.132	0.046	-0.114	-0.021
8	0.891	-0.522	0.458	0.138	-0.370	-0.220	0.091	0.006	0.050	0.041	0.438
3	0.935	0.038	-0.878	-0.024	0.315	-0.038	-0.022	-0.073	0.022	0.173	-0.158
1	0.956	0.391	-0.781	-0.106	-0.342	0.105	-0.115	-0.069	0.019	0.188	0.026
6	0.962	-0.439	-0.722	0.144	-0.148	-0.225	0.126	-0.353	0.107	-0.029	0.035
7	0.965	-0.418	0.624	0.163	-0.203	-0.223	0.101	-0.060	0.518	0.002	0.042
11	0.884	-0.009	-0.069	-0.909	0.090	0.033	-0.096	-0.030	0.002	0.177	-0.056
12	0.904	-0.026	0.023	-0.886	-0.196	0.057	-0.203	-0.048	0.067	-0.168	0.018
21	0.897	-0.227	0.275	0.742	0.040	-0.277	0.212	-0.035	0.182	-0.247	0.018
2	0.925	-0.006	-0.233	-0.055	0.905	0.018	-0.094	-0.056	0.018	-0.069	-0.179
9	0.917	-0.119	-0.027	-0.266	-0.789	0.189	-0.260	-0.035	0.001	0.226	-0.232
19	0.891	-0.193	0.148	0.172	0.123	-0.844	0.178	0.038	-0.109	-0.174	0.026
20	0.875	-0.171	0.331	0.470	0.118	-0.478	0.195	-0.050	0.060	-0.474	0.072
13	0.952	0.125	-0.104	-0.317	-0.111	0.126	-0.882	-0.023	0.051	0.119	0.047
22	0.880	-0.241	0.269	0.388	-0.215	-0.384	0.560	-0.017	0.100	-0.127	0.254
16	0.971	-0.169	0.032	-0.053	0.027	0.012	-0.020	-0.939	0.233	0.025	0.023
17	0.976	-0.238	0.023	-0.005	0.048	0.099	-0.041	-0.275	0.910	-0.017	0.036
10	0.904	0.079	-0.312	-0.138	-0.342	0.240	-0.182	-0.029	-0.009	0.757	-0.009

High loadings (over ± 0.700 are underscored)

Table 3. The nine factors with the percentage of explained variance >5% 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	89.5	

temp. = temperature °C; Prec. = precipitation; Def. = Deficiency

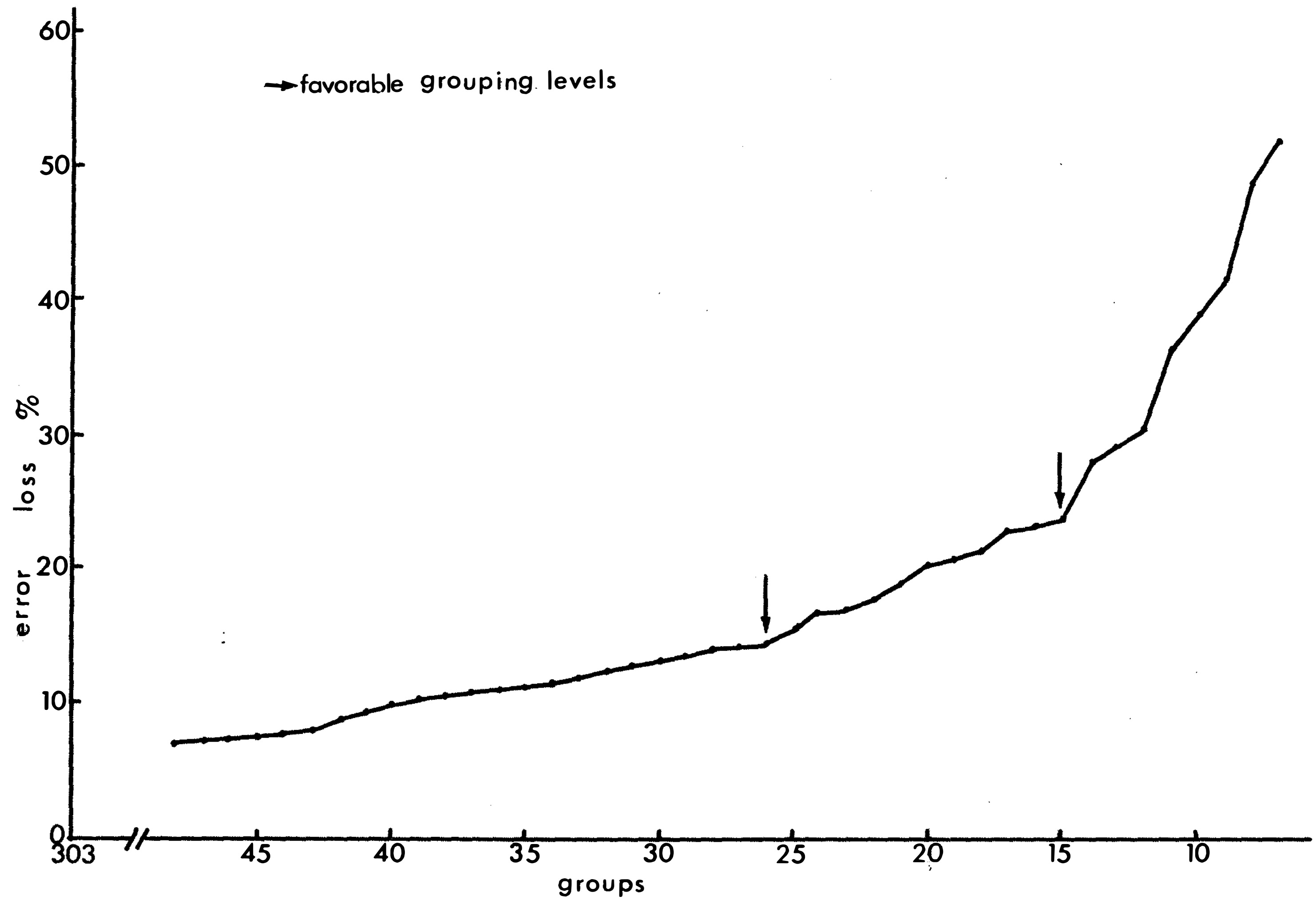


Fig. 7. Number of groups and percentage of accumulated within-group variation or error.

Creek R.S.) because of suspected errors in their data; a few other stations have been retained in an indicated group or zone although their grouping may suggest inconsistent data. Table 4 indicates how the 26 groups of Figure 8 and Appendix A would combine to provide fewer groups at each subsequent step to reduce the number of groupings.

In the grouping analysis, several stations were isolated from the main cluster of stations in their group, often being located within the boundary of another group. Several of these stations were retained as outliers of their groups, but 5 stations (indicated by an asterisk in Appendix A) were included in the dominant surrounding groups or zones in drawing the map because the anomalies could plausibly be attributed to localized climatic and topographical characteristics, and the hierarchical grouping procedure indicated their close relationship to the group containing the proximate stations. Because only one of these stations included generated values, estimation of missing values was not considered an important reason for the designation as local climate types. Four stations in Alberta were, however, considered as separate areas or disjunct groups, and were maintained as individual climatic areas because they represent mountain pass and river valley climates that are characteristic of the Rocky Mountain areas.

The Wilk's Lambda test yielded an F-ratio value of 29.05, which comfortably exceeded the table value for F, and the null hypothesis at the 99.9% significance level was rejected. The 26 climatic groups are therefore separate and mutually exclusive.

The importance of each factor to each of the nine linear discriminant functions is presented in Table 5. The cutoff limit of 1.00 for the eigenvalues if they explained at least 5% of the variance, used to denote the significant factors, was tested by discriminant analysis. On this basis, it was determined that the nine factors used to define and characterize the climate are significant, accounting for 100% of the explained variance. However, the last discriminant function contributed only 2.35% of the explained total variance and had an eigenvalue of 0.72, thereby indicating that factor 8 (August frequency of days >-2.2°C) is not a major significant discriminating variable between groups.

Table 6 provides a general idea of the mean and interstation variability of climate for the 26 groups or zones in the study area. The

Table 4. How the 26 groups of Figure 8 and Appendix A would combine to provide a classification with from 12 to 25 groups

25 Groups	-	Groups 7 and 9 combine
24 Groups	-	Groups 23 and 26 combine
23 Groups	-	Groups 8 and 13 combine
22 Groups	-	Groups 20 and 22 combine
21 Groups	-	Groups 11 and 16 combine
20 Groups	-	Group 4 combines with 11 and 16
19 Groups	-	Groups 14 and 18 combine
18 Groups	-	Groups 1 and 5 combine
17 Groups	-	Groups 12 and 17 combine
16 Groups	-	Group 25 combines with 23 and 26
15 Groups	-	Group 15 combines with 14 and 18
14 Groups	-	Group 6 combines with 4, 11 and 16
13 Groups	-	Group 24 combines with 23, 25 and 26
12 Groups	-	Group 10 combines with 14, 15 and 18

Table 5. Nine linear discriminant functions, their percentage of total explained variance, and the relative contribution of the nine factors to each

Discriminant Function No.	% Explained Variance	Factors								
		1	2	3	4	5	6	7	8	9
1	27.17	3.6	<u>-5.6</u>	1.0	-0.7	0.1	-0.4	1.0	-0.1	2.7
2	19.92	2.7	2.1	1.6	<u>-6.2</u>	0.7	-0.3	1.3	0.8	1.1
3	13.28	2.4	1.5	1.5	2.6	2.8	0.3	<u>6.5</u>	-1.0	0.2
4	10.18	0.0	0.1	-1.9	-0.3	<u>-6.9</u>	<u>5.0</u>	2.9	0.5	0.7
5	8.69	-1.3	1.2	4.5	1.2	0.5	3.1	-1.7	0.4	<u>6.9</u>
6	7.35	<u>4.5</u>	0.8	<u>5.0</u>	1.4	-3.0	-0.3	-2.5	-2.9	-3.1
7	5.65	<u>-5.1</u>	-1.5	<u>6.0</u>	-1.0	-0.9	-0.7	2.4	1.8	-2.7
8	5.41	1.3	-0.7	0.3	-0.3	3.7	<u>7.7</u>	-1.0	2.2	-3.1
9	2.35	1.9	0.5	0.2	0.6	-0.5	-1.4	0.5	<u>7.3</u>	0.6

* underscored numbers indicate the most significant factor or factors in each discriminant function (a description of the variables in each factor is listed in Table 3).

Table 6. The 26 climatic groups, with the mean value and range of values of the climatic significant variables for each group

Group No. Mean & Range	May Min. T.[1] >-2.2°C (Days)	May Mean Temp.[1] (°C)	June Min. T.[1] >-2.2°C (Days)	Long.[1] (Deg.[1] West)	Elev.[1] a.s.l. (m)	July Mean Temp.[1] (°C)	July Ppt.[1] (mm)	Aug. Ppt.[1] (mm)	Aug. Water Def.[1] (mm)	Lat.[1] (Deg.[1] North)	May Ppt.[1] (mm)	June Water Def.[1] (mm)	Sept. Ppt.[1] (mm)	July Min. T.[1] >-2.2°C (Days)	Aug. Min. T.[1] >-2.2°C (Days)
(1)															
MEAN	27.5	9.3	29.4	118.17	588	15.7	65.3	49.8	51.8	56.22	33.5	17.3	43.2	30.8	30.8
RANGE	23.2-29.8	8.8-9.7	26.9-30.0	115.26-122.35	279-1093	14.4-16.7	50.8-86.4	38.1-66.0	43.2-63.0	55.11-58.50	20.3-48.3	7.4-36.1	33.0-68.6	30.0-31.0	30.2-31.0
(2)															
MEAN	25.7	8.8	29.1	111.87	638	15.6	81.3	59.4	31.0	54.21	38.9	4.6	37.6	30.8	30.8
RANGE	23.3-29.1	4.9-10.5	26.6-30.0	107.46-115.35	482-792	13.2-16.9	53.3-114.3	33.0-71.1	0.0-57.2	53.08-56.37	22.9-50.8	0.0-15.0	28.2-43.2	30.0-31.0	29.9-31.0
(3)															
MEAN	24.4	7.5	29.2	114.01	1340	14.8	43.9	38.9	42.7	49.72	72.9	0.3	52.8	30.8	30.6
RANGE	17.0-29.1	4.8-9.7	26.3-30.0	113.19-115.03	1152-1661	12.7-17.7	30.5-68.6	22.9-50.8	0.0-76.2	49.00-51.02	58.4-86.4	0.0-2.3	38.1-73.7	29.7-31.0	27.6-31.0
(4)															
MEAN	28.0	7.8	29.8	117.86	1014	14.1	93.2	87.1	15.7	54.52	53.6	2.8	67.3	30.9	30.9
RANGE	22.1-29.8	6.1-9.2	28.5-30.0	115.37-119.24	762-1274	12.1-15.1	71.1-116.8	68.6-104.1	0.0-29.0	54.14-55.13	43.2-63.5	0.0-7.6	45.7-86.4	30.4-31.0	30.0-31.0
(5)															
MEAN	26.5	9.7	29.7	108.24	568	16.9	73.7	53.3	49.0	52.96	33.0	16.3	40.6	31.0	30.9
RANGE	21.8-28.9	7.3-10.5	28.2-30.0	101.54-114.06	358-848	14.3-18.4	53.3-96.5	43.2-71.1	27.9-67.6	51.15-54.46	17.8-45.7	5.1-28.4	25.4-55.9	30.6-31.0	29.9-31.0
(6)															
MEAN	26.4	8.3	29.7	115.05	875	14.2	91.4	79.0	19.8	54.22	43.9	6.1	38.4	30.8	30.8
RANGE	24.4-29.1	7.2-9.2	29.1-30.0	111.43-118.04	610-1272	12.4-15.2	63.5-116.8	66.0-94.0	7.9-37.8	53.11-55.04	30.5-53.3	0.3-14.0	33.0-48.3	30.1-31.0	29.6-31.0

Table 6. (Continued)

Group No. Mean & Range	May Min. T.[1] >-2.2°C (Days)	May Mean Temp.[1] (°C)	June Min. T.[1] >-2.2°C (Days)	Long.[1] (Deg.[1] West)	Elev.[1] a.s.l. (m)	July Mean Temp.[1] (°C)	July Ppt.[1] (mm)	Aug. Ppt.[1] (mm)	Aug. Water Def.[1] (mm)	Lat.[1] (Deg.[1] North)	May Ppt.[1] (mm)	June Water Def.[1] (mm)	Sept. Ppt.[1] (mm)	July Min. T.[1] >-2.2°C (Days)	Aug. Min. T.[1] >-2.2°C (Days)
(7)															
MEAN	20.1	5.2	29.4	110.80	211	15.7	49.8	43.7	58.7	60.02	18.8	9.9	40.1	30.9	30.7
RANGE	16.2-21.9	4.2-7.0	28.6-29.9	105.46-115.46	161-312	14.9-16.2	45.7-55.9	25.4-63.5	35.3-77.2	59.16-61.10	12.7-25.4	3.3-14.5	33.0-45.7	30.9-31.0	29.7-31.0
(8)															
MEAN	20.1	4.2	28.6	114.90	1550	11.6	110.7	65.0	3.8	51.54	67.1	0.0	53.8	30.0	30.6
RANGE	17.0-24.0	1.9-6.8	27.8-29.6	114.47-115.25	1280-1905	9.9-13.3	96.5-127.0	50.8-78.7	0.0-12.7	51.19-52.08	53.3-81.3	0.0	43.2-66.0	29.1-31.0	30.4-30.9
(9)															
MEAN	21.7	6.3	29.5	107.25	370	15.7	69.1	59.9	37.8	56.56	35.1	2.8	63.5	30.9	30.8
RANGE	13.3-26.9	2.4-9.2	28.9-30.1	98.38-118.57	233-945	13.6-17.3	55.9-88.9	45.7-78.7	26.9-51.8	54.55-58.46	27.9-40.6	0.0-8.4	53.3-76.2	30.5-31.0	30.0-31.0
(10)															
MEAN	12.7	0.1	25.4	117.47	1768	10.1	95.3	72.9	10.4	52.94	48.5	1.5	56.4	30.1	29.4
RANGE	7.8-17.1	-9.4-5.7	21.4-27.9	115.57-119.53	1326-2210	8.5-12.1	68.6-127.0	40.6-104.1	0.0-34.3	51.15-55.04	35.6-76.2	0.0-10.2	40.6-83.8	28.9-30.5	27.5-30.8
(11)															
MEAN	23.5	6.6	29.4	118.04	773	14.0	69.6	44.5	47.0	56.38	30.7	4.6	39.4	30.5	30.6
RANGE	19.4 27.5	4.1-8.5	28.2-30.0	115.07-119.33	304-1219	12.5-14.9	50.8-86.4	25.4-61.0	23.6-75.7	56.19-56.58	17.8-40.6	0.0-13.5	33.0-43.2	29.3-31.0	29.6-31.0
(12)															
MEAN	15.5	3.2	26.7	114.84	1575	12.9	61.7	49.0	11.2	50.72	68.6	0.0	54.1	30.6	29.5
RANGE	13.4-16.8	-1.7-5.8	26.0-28.1	114.42-115.07	1433-1829	12.4-13.5	40.6-76.2	43.2-58.4	0.0-33.3	50.54-51.03	58.4-81.2	0.0	45.7-58.4	30.4-31.0	28.6-30.3
(13)															
MEAN	23.7	5.6	29.5	116.63	1320	13.4	115.1	98.6	3.0	53.63	63.0	0.3	62.2	30.9	30.8
RANGE	17.7-28.7	1.3-8.1	28.4-30.1	115.09-118.11	1036-1631	12.3-14.4	99.1-132.1	71.1-124.5	0.0-19.3	52.47-54.55	48.3-68.6	0.0-0.3	50.8-73.7	30.5-31.0	30.3-31.0
(14)															
MEAN	27.0	8.3	29.5	113.58	887	14.8	116.1	76.2	8.6	54.43	51.6	1.5	56.9	30.9	30.8
RANGE	25.0-28.9	6.6-9.3	28.5-30.0	111.11-115.25	584-1113	14.1-15.6	88.9-134.6	68.6-91.4	0.0-22.1	52.23-55.49	40.6-68.6	0.0-7.9	43.2-71.1	30.3-31.0	30.1-31.0

Table 6. (Continued)

Group No. Mean & Range	May Min. T.[1] >-2.2°C (Days)	May Mean Temp.[1] (°C)	June Min. T.[1] >-2.2°C (Days)	Long.[1] (Deg.[1] West)	Elev.[1] a.s.l. (m)	July Mean Temp.[1] (°C)	July Ppt.[1] (mm)	Aug. Ppt.[1] (mm)	Aug. Water Def.[1] (mm)	Lat.[1] (Deg.[1] North)	May Ppt.[1] (mm)	June Water Def.[1] (mm)	Sept. Ppt.[1] (mm)	July Min. T.[1] >-2.2°C (Days)	Aug. Min. T.[1] >-2.2°C (Days)
(15)															
MEAN	24.6	6.7	29.3	109.85	677	14.5	91.7	57.9	23.9	56.78	39.6	0.3	55.4	30.7	30.3
RANGE	20.0-	4.2-	26.8-	108.29-	421-	10.6-	73.7-	38.1-	0.0-	55.20-	33.0-	0.0-	48.3-	29.3-	28.3-
	28.1	8.8	30.2	119.10	853	16.2	111.8	73.7	54.6	58.35	48.3	3.6	63.5	31.0	31.0
(16)															
MEAN	20.0	3.3	28.8	112.92	700	13.6	94.0	71.1	14.5	57.00	37.6	2.8	38.1	30.9	29.9
RANGE	19.3-	-6.7-	27.3-	111.32-	349-	11.8-	88.9-	63.5-	0.0-	56.18-	33.0-	0.0-	27.9-	30.6-	29.2-
	35.7	5.5	54.2	115.40	911	15.1	99.1	81.3	22.6	57.27	43.2	7.6	48.3	31.0	30.6
(17)															
MEAN	11.8	-2.5	23.6	114.67	1918	11.5	45.7	43.2	24.9	50.35	47.0	0.0	49.5	30.2	28.6
RANGE	6.7-	-10.4-	21.2-	114.27-	1463-	9.6-	40.6-	43.2	16.5-	50.10-	27.9-	0.0	45.7-	30.0-	28.6
	16.8	5.5	26.0	115.07	2373	13.5	50.8		33.3	50.59	60.0		53.3	30.4	
(18)															
MEAN	23.4	5.8	28.4	111.86	727	14.5	108.0	71.9	5.3	56.54	45.2	0.8	77.0	30.9	30.9
RANGE	20.0-	4.2-	27.2-	111.14-	604-	13.8-	99.1-	61.0-	0.0-	56.07-	30.5-	0.0-	53.3-	30.6-	30.6-
	25.9	7.6	29.6	113.45	780	15.1	121.9	86.4	21.1	57.31	58.4	2.5	94.0	31.0	31.0
(19)															
MEAN	25.3	8.7	28.8	101.84	454	16.7	65.5	57.4	46.7	51.45	41.4	2.5	39.4	30.3	30.1
RANGE	18.8-	6.5-	26.8-	97.20-	223-	14.5-	50.8-	35.6-	30.5-	49.52-	22.9-	0.0-	25.4	28.8-	27.8-
	27.9	10.0	29.8	107.22	622	18.0	83.8	83.8	72.4	53.27	66.0	17.3	48.3	31.0	31.0
(20)															
MEAN	20.8	6.3	27.4	100.04	274	14.4	66.0	55.9	42.9	53.34	35.6	6.4	44.2	27.7	29.2
RANGE	17.9-	4.3-	2 .6-	97.35-	231-	13.2-	53.3-	38.1-	23.9-	51.12-	25.4-	0.0-	38.1-	26.8-	27.8-
	23.3	8.0	29.1	102.18	340	15.8	76.2	76.2	53.1	56.51	58.4	12.7	53.3	29.0	30.8
(21)															
MEAN	20.6	5.4	27.3	117.40	511	14.1	101.6	43.2	3.0	58.73	30.5	0.0	41.9	30.5	30.3
RANGE	20.3-	5.0-	25.4-	117.38-	320-	14.0-	78.7-	33.0-	0.0-	58.39-	25.4-	0.0	35.6-	30.2-	30.0-
	20.8	5.8	29.2	117.42	701	14.2	124.5	53.3	5.8	59.07	35.6		48.3	30.9	30.7
(22)															
MEAN	24.5	8.6	28.0	108.76	594	11.7	71.9	53.3	41.1	53.57	27.2	5.8	34.8	26.9	30.7
RANGE	22.4-	7.1-	26.6-	108.15-	506-	10.2-	68.6-	48.3-	27.9-	53.19-	25.4-	0.0-	25.4-	26.1-	30.5-
	26.6	9.6	28.9	109.14	690	13.8	73.7	58.4	53.3	54.24	27.9	8.9	45.7	28.4	31.0

Table 6. (Continued)

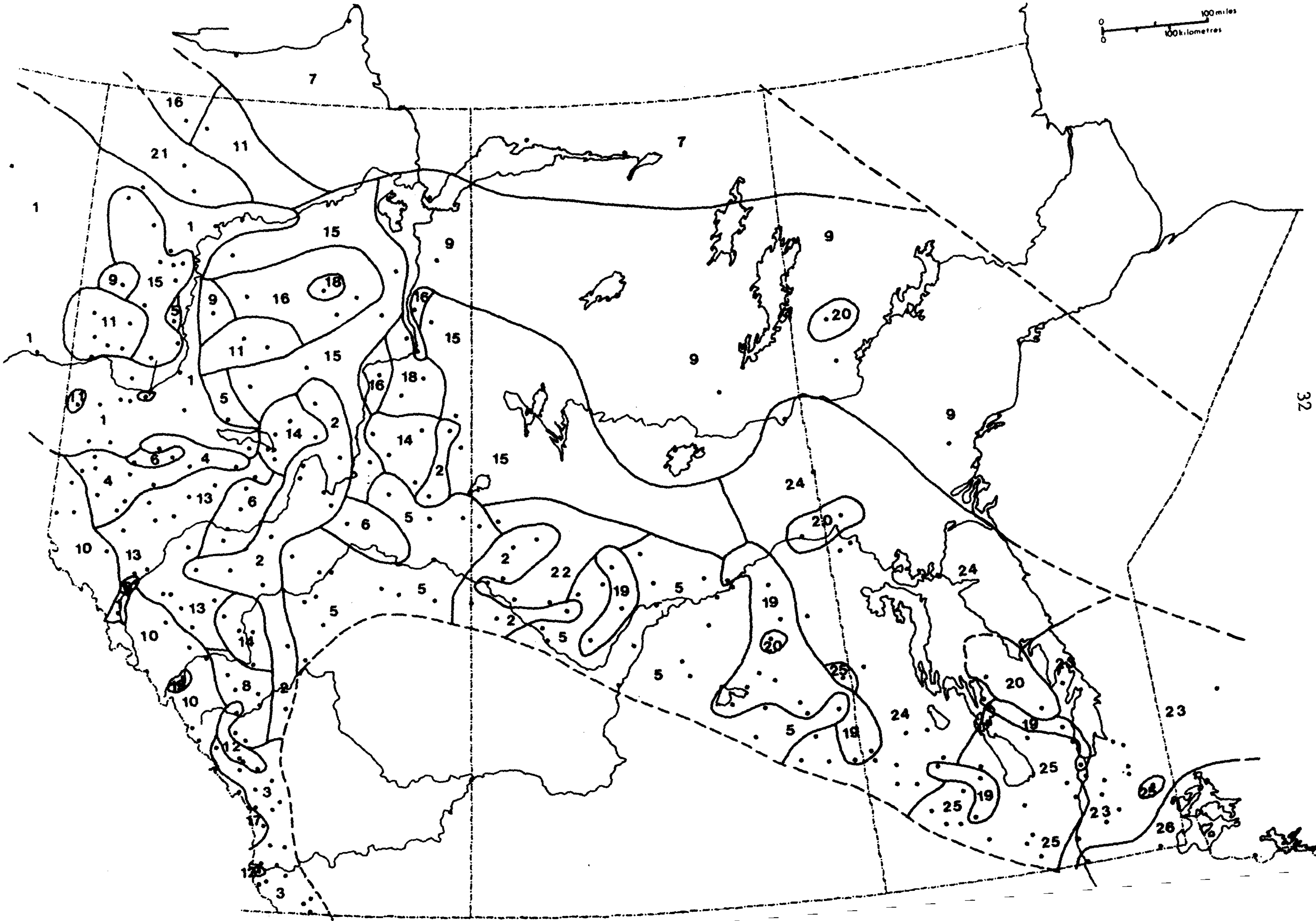
Group No. Mean & Range	May Min. T.[1] >-2.2°C (Days)	May Mean Temp. (°C)	June Min. T.[1] >-2.2°C (Days)	Long.[1] (Deg. West)	Elev.[1] a.s.l. (m)	July Mean Temp. (°C)	July Ppt. (mm)	Aug. Ppt. (mm)	Aug. Water Def. (mm)	Lat.[1] (Deg. North)	May Ppt. (mm)	June Water Def. (mm)	Sept. Ppt. (mm)	July Min. T.[1] >-2.2°C (Days)	Aug. Min. T.[1] >-2.2°C (Days)
(23)															
MEAN	26.5	9.2	29.6	96.11	262	18.7	80.8	73.2	36.8	50.07	69.9	2.5	51.3	30.8	30.7
RANGE	24.6-27.7	7.9-10.2	28.3-30.0	93.49-97.22	219-381	18.1-19.6	71.1-94.0	55.9-88.9	6.9-57.4	49.21-51.40	53.3-81.3	0.0-7.9	45.7-63.5	30.4-31.0	29.8-31.0
(24)															
MEAN	25.2	8.4	29.7	101.32	436	17.1	74.4	63.0	39.9	51.90	42.7	10.4	52.1	30.7	30.8
RANGE	21.1-27.0	6.3-9.4	28.6-30.0	98.48-109.03	223-756	14.6-18.3	53.3-96.5	48.3-86.4	11.2-56.1	50.25-55.32	25.4-68.6	2.0-21.1	40.6-73.7	29.0-31.0	30.2-31.0
(25)															
MEAN	27.2	9.8	29.8	98.54	325	19.1	83.3	73.4	42.7	49.70	58.4	9.1	40.9	30.9	30.9
RANGE	25.8-28.1	9.4-10.5	29.5-30.0	97.14-100.19	239-473	18.6-20.0	53.3-106.7	53.3-91.4	27.9-55.9	49.11-50.52	43.2-76.2	4.6-13.0	35.6-48.3	30.6-31.0	30.6-31.0
(26)															
MEAN	26.6	9.4	29.1	95.06	328	18.9	110.7	80.8	24.6	49.05	71.6	7.1	68.6	31.0	30.3
RANGE	24.5-28.4	8.7-10.8	26.3-30.0	93.48-97.12	241-410	18.4-20.1	88.9-154.9	50.8-106.7	6.4-51.1	48.38-49.48	66.0-78.7	5.8-10.9	58.4-81.3	31.0	28.1-31.0

[1] Abbreviations used: Long. = Longitude; Lat. = Latitude; Elev. a.s.l. = Elevation above sea level; Deg. = Degrees; T. and Temp. = Temperature; Ppt. = Precipitation; Water Def. = Water Deficiency; Min. = Minimum

15 significant variables in Table 6 are listed in the approximate order used to characterize the climate. Thus, the first 3 (May frequency of days with minimum temperature >-2.2°C, May mean temperature, and June number of days >-2.2°C), are considered the most important discriminating variables because they contribute to the first factor (Table 3). August frequency of days >-2.2°C is the least important discriminating variable. The sixteenth variable, not shown in Table 6 and not a major discriminating variable, was June precipitation (see Table 3). The other six input variables (June, August, September mean temperature; September frequency of days >-2.2°C; July and September water deficiency) were not important discriminating climatic variables in this analysis.

A map delineating the climatic groups or zones in the forested and fringe areas of the Prairie Provinces is the final product of the study (Fig. 8). It represents the pattern of climatic groupings obtained using the statistically important variables between groups to assist in boundary placement. To aid in the placement, t-tests at the 95% confidence level were performed on 218 intergroup mean comparisons of significant variables across 89 boundary lines separating 26 climatic groups, of which 186 were statistically significant. The means and standard deviations of distinguishing variables are presented for all pairs of adjacent groups in Appendix B.

Accurate placement of the boundary between two climatic groups is relatively straightforward when one significant variable is involved, but becomes more complicated when more than one variable is important in delimiting the boundary. For example, the variables May days >2.2° C, May temperature, elevation, and July temperature are essential to establishing the boundary between climatic groups 8 and 14 in Alberta (see Appendix B). Clearwater Lookout in group 8 has a May >-2.2° value of 19.1 days, while Rocky Mountain House in group 14 has a value of 28.0 days. The average value of group 8 and 14 May >-2.2° readings is 23.5 days. This value is used to form the boundary between these two stations. The May temperature and elevational variables tend to move the boundary closer to the group 8 Clearwater station. July temperature, however, acts to shift the boundary the same way as the May >-2.2° C values. As a result, the final boundary between the stations is closer to Clearwater. The


0
100 miles
0
100 kilometres

same methods and variables were used to determine the placement of the boundary between Rocky Mountain House, Baseline Lookout, and Burnstick Lookout; and between Alder Flats Lookout and Baseline Lookout. The same methods were utilized in determining the boundary placement of all climatic groups, but the variables differed.

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APPENDIX A. Stations by climatic grouping, with elevation and location.

STATION	ELEVATION (m)	LATITUDE (Degrees, Minutes)	LONGITUDE (Degrees, Minutes)
Group 1			
Assumption	320	58,42	118,41
Beaverlodge CDA	762	55,11	119,22
Fairview	658	56,04	118,23
Falher	582	55,44	117,12
Fort Nelson A.	375	58,50	122,35
*Fort Saskatchewan	625	53,43	113,10
Fort St. John A.	693	56,14	120,44
Fort Vermillion CDA	279	58,23	116,03
Grande Prairie A.	668	55,11	118,53
High Prairie	599	55,26	116,29
Jasper	1061	52,53	118,04
Keg River	427	57,47	117,52
Kinuso R.S.	590	55,20	115,26
Peace River A.	568	56,14	117,26
*Prince	536	52,58	108,22
Rycroft	604	55,45	118,47
Wanham Exp. Sta.	607	55,43	118,22
White Mountain Lo.	1184	55,42	119,14
Group 2			
Athabasca	579	54,49	113,32
Calling Lake R.S.	594	55,15	113,11
Campsie	671	54,08	114,41
Chisholm Lo	671	54,56	114,02
Cold Creek R.S.	792	53,37	115,35
Edson A.	1016	53,35	116,25
Gordon Lake Lo.	488	56,37	110,30
Lloydminster	646	53,17	110,00
Loon Lake CDA EPF	594	54,04	109,03
Meadow Lake	482	54,07	108,26
Meanook	686	54,37	113,21
Moon Lake	762	53,28	114,59
Olds	1040	51,47	114,06
Rabbit Lake	747	53,09	107,46
Rimbey	914	52,38	114,13
Sand River Lo.	732	54,39	110,59
St. Walburg	640	53,38	109,13
Smith R.S.	564	55,10	114,02
Wabasca R.S.	545	55,58	113,50
Waseca	648	53,08	109,24

Group 3

Banff	1397	51,11	115,34
Beaver Mines	1286	49,28	114,10
Caldwell	1311	49,09	113,38
Cardston	1166	49,13	113,19
Carway	1359	49,00	113,22
Castle R.S.	1364	49,24	114,20
Coleman R.S.	1341	49,39	114,30
Cowley	1195	49,41	114,07
High River	1152	50,29	114,10
Highwood R.S.	1491	50,23	114,38
Kananaskis Bdry. R.S.	1463	50,59	115,07
Livingstone Gap R.S.	1417	49,53	114,23
Pekisko	1439	50,22	114,25
Pincher Creek	1155	49,30	113,57
Porcupine/Skyline R.S.	1661	49,53	113,58
Sheep R.S.	1494	50,39	114,39
Turner Valley	1219	50,43	114,21

Group 4

Bald Mountain Lo.	939	54,49	118,55
Economy Lo.	800	54,47	118,14
House Mountain Lo.	1152	55,02	115,37
Kakwa Lo.	1213	54,26	118,58
Pinto Lo.	1067	54,47	119,21
Puskwaskau Lo.	972	55,13	117,30
Simonette Lo.	1274	54,14	118,25
Smoky Lo.	1158	54,24	118,18
Snuff Mountain Lo.	969	54,41	117,32
South Wapiti R.S.	762	54,56	119,12
Sweathouse Lo.	853	54,55	116,45

Group 5

Calmar	671	53,15	113,50
Cold Lake A.	513	54,25	110,17
Edmonton Int. A.	719	53,19	113,35
Edmonton Namao A.	699	53,40	113,28
Elk Point	585	53,53	110,54
Humbolt	568	52,12	105,07
Iron River	579	54,25	111,00
Kamsack	440	51,34	101.54
Kelliher CDA EPF	676	51,15	103.44
Lacombe CDA	848	52,28	113,45
Lac La Biche A.	559	54,46	112,10
Lost River	387	53,17	104,19
Manning R.S.	460	56,55	117,36
Melfort CDA	480	52,49	104,36

Group 5 cont.

Nipawin	358	53,21	104,01
North Battleford A.	547	52,46	108,55
Northside	494	53,32	105,46
Pierceland	549	54,21	109,45
Pilger	544	52,25	105,09
Prince Albert A.	431	53,13	105,41
Ranfurly	686	53,27	111,39
Rosthern	510	52,40	106,20
Saskatoon A.	501	52,10	106,41
Salt Prairie Lo.	716	55,40	115,50
Sion	698	53,54	114,06
Snowden CDA EPF	447	53,32	104,41
Spiritwood	587	53,22	107,31
Vegreville CDA	636	53,29	112,02
Vermilion A.	621	53,21	110,50
Victoire	521	53,29	107,02
Waskesiu Lake	532	53,55	106,05
Wetaskiwin	762	52,58	113,20

Group 6

Debolt R.S.	610	54,56	118,04
Entrance	1006	53,22	117,42
Newbrook	671	54,20	112,57
Pimple Lo.	1103	54,30	115,28
Swan Dive Lo.	1272	54,44	115,13
Valleyview R.S.	762	55,04	117,16
Vilna	640	53,11	111,43
Whitecourt	741	54,08	115,40
Whitecourt Lo.	1201	54,02	115,43

Group 7

Fort Resolution	167	61,10	113,41
Fort Smith A.	202	60,01	111,58
Hay River A.	161	60,51	115,46
Stony Rapids	213	59,16	105,46
Uranium City A.	312	59,34	108,29

Group 8

Baseline Lo.	1897	52,08	115,25
Burnstick Lo.	1219	51,58	114,47
Clearwater R.S.	1280	51,59	115,14
Ghost R.S.	1448	51,19	114,57
Mockingbird Lo.	1905	51,26	115,05

Group 9

Bison Tower Lo.	610	57,05	116,32
Brabant Lake	308	56,00	103,43
Brochet	351	57,53	101,40
Fort Chipewyan A.	228	58,46	110,07
Fort McMurray A.	370	56,39	111,13
Hotchkiss Lo.	948	57,20	118,57
Laurie River Power	305	56,14	100,59
La Ronge	369	55,06	105,18
Richardson Lo.	305	57,55	110,58
Wabowden	233	54,55	98,38
Whitesand	358	56,20	103,15

Group 10

Adams Creek Lo.	2210	53,43	118,34
Baldy Lo.	2083	52,33	116,07
Copton Lo.	1856	54,11	119,24
Grave Flats Lo.	2074	52,51	117,00
Lake Louise	1534	51,25	116,10
Mt. Eisenhower	1425	51,15	115,57
Nordegg R.S.	1326	52,29	116,05
Nose Mountain Lo.	1574	54,33	119,35
Torrens Lo.	1829	55,04	119,53

Group 11

Clear Hills Lo.	933	56,36	119,25
Doig Tower Lo.	1219	56,58	119,33
Eureka River	617	56,28	118.45
Notikewin Lo.	762	56,52	118,35
Oregon Flats	671	56,19	119,29
Otter Lakes Lo.	732	56,42	115,46
Red Earth Lo.	610	56,40	115,07
Saddle Hills Lo.	960	55,37	119,43
Steen River R.S.	304	59,38	117,10
Worsley R.S.	640	56,30	119,08

Group 12

Elbow R.S.	1433	50,54	114,42
Ironstone Lo.	2073	49,34	114,28
Kananaskis	1390	51,02	115,03
Pigeon Lo.	1828	51,03	115,04
Red Deer R.S.	1451	51,40	115,13

Group 13

Athabasca Lo.	1631	53,25	117,47
Berland Lo.	1219	54,15	117,24
Blackstone Lo.	1570	52,47	116,21
Deer Mountain Lo.	1122	54,55	115,09
Eagle Lo.	1042	54,28	116,25
Goose Mountain Lo.	1402	54,45	116,04
Huckleberry Lo.	1429	53,59	118,11
Lovett Lo.	1445	53,05	116,41
Mayberne Lo.	1490	53,52	116,40
Obed Lo.	1585	53,34	117,30
Pass Creek Lo.	1135	54,14	116,50
Robb R.S.	1130	53,14	116,58
Tony Creek Lo.	1036	54,23	117,24
Wolf Lake Lo.	1099	53,09	115,54
Yellowhead Lo.	1463	53,14	117,09

Group 14

Alder Flats Lo.	1076	52,48	114,49
Brazeau Lo.	1088	53,01	115,25
Conklin Lo.	671	55,37	111,11
Doucette Lo.	610	55,49	114,18
Flattop Lo.	1030	55,09	114,48
Heart Lake Lo.	887	55,00	111,20
May Lo.	896	55,37	112,20
Marten Mountain Lo.	899	55,30	114,42
O'Chiese Lo.	1113	52,47	115,20
Pelican Mountain Lo.	914	55,37	113,34
Rocky Mountain House	1015	52,23	114,50
Round Hill Lo.	750	55,18	111,59
Wagner	583	55,21	114,59

Group 15

Bassett Lo.	755	58,12	118,13
Battle River Lo.	732	57,29	117,39
Birch Mountain Lo.	610	57,43	111,51
Buffalo Lo.	792	57,57	116,13
Buffalo Narrows	421	55,52	108,29
Chinchaga Lo.	762	57,07	118,20
Codesa Lo.	792	55,40	118,05
Cowpar Lo.	563	55,50	110,23
Deadwood Tower Lo.	610	56,38	117,21
Ells Lo.	610	57,11	112,20
Hawk Hills	610	57,39	117,25
Keg Lo.	762	57,39	118,02
Muskeg Lo.	652	57,08	110,54
Naylor Hills Lo.	732	57,40	117,43

Group 15 con't

*Sundre R.S.	1128	51,46	114,38
Teepee Lo.	645	56,28	114,07
Wandering River R.S.	564	55,12	112,30
Whitefish Lo.	610	56,11	115,28
Whitemud Lo.	853	56,26	118,01
Winefred Lo.	744	55,20	110,12
Zama Tower Lo.	610	58,35	119,10

Group 16

Bitumount Lo.	349	57,22	111,32
Grande Lo.	533	56,18	112,13
Legend Lo.	911	57,27	112,53
Seaforth Lo.	823	57,14	113,21
Steen Lo.	707	59,38	117,47
Talbot Lo.	884	57,20	115,40

Group 17

Hailstone Butte Lo.	2373	50,10	114,27
Kananaskis Lo.	2072	50,37	115,04

Group 18

Algar Lo.	780	56,07	111,47
Jean Lo.	762	57,31	113,45
*Slave Lake R.S.	586	55,17	114,38
Stoney Mountain Lo.	762	56,23	111,14
Thickwood Lo.	604	56,53	111,39

Group 19

Arborg	227	50,55	97,20
Buchanan	503	51,43	102,50
Carberry	385	49,52	99,21
Good Spirit Lake	488	51,30	102,38
Hafford	595	52,44	107,22
Inglis	561	50,54	101,15
Kelvington	559	52,09	103,30
Langenburg CDA EPF	514	50,46	101,41
Lintlaw	611	52,05	103,16
Moose Horn	250	51,18	98,37
Parkside CDA EPF	515	53,14	106,35
Paswegin	530	51,59	103,57
Petersfield	223	50,19	96,59

Group 19 con't

Plumas	283	50,23	99,05
Prairie River	472	52,52	102,59
Smoky Burn CDA EPF	361	53,20	103,08
*Sturgeon Crossing	610	53,43	106,43
Upper Saskatchewan R.S.	1298	52,11	116,27
Wasagaming	622	50,39	99,58
White Fox CDA EPF	372	53,27	104,05
Wynyard	561	51,46	104,12

Group 20

Cumberland House	271	53,58	102,18
Gypsumville	267	51,40	98,44
Hodgson	231	51,12	97,35
Lynn Lake	340	56,51	101,02
*Porcupine Plains	498	52,39	103,12
Wanless	261	54,11	101,22

Group 21

*Frenchman Butte	550	53,35	108,38
Upper Hay River R.S.	320	59,07	117,42
Watt Mountain Lo.	701	58,39	117,02

Group 22

Glaslyn CDA EPF	690	53,19	108,15
Goodsoil	506	54,24	109,14
Turtleford CDA EPF	587	53,27	109,00

Group 23

Beausejour	274	50,04	96,32
Dugald Briarwood	257	49,53	96,39
Great Falls	249	50,28	96,00
Morris	237	49,21	97,22
Pinawa WNRE	267	50,11	96,03
Pine Dock	219	51,40	96,51
Pine Falls	229	50,34	96,13
Red Lake A.	381	51,04	93,49
Selkirk	225	50,09	96,53
Seven Sisters Falls	267	50,07	96,01
Ste Genevieve	274	49,45	96,31
Steinbach	268	49,31	96,41

Group 24

Bangor	532	50,51	102,14
Birtle	546	50,25	100,50
Dauphin A.	304	51,06	100,03
Flin Flon	335	54,46	101,51
Foam Lake	594	54,04	109,03
Gilbert Plains	404	51,06	100,28
Grand Rapids	223	53,09	99,17
Hudson Bay	372	52,52	102,24
Island Falls	299	55,32	102,21
Melville	553	50,58	102,48
Pasquia Project PFRA	261	53,43	101,30
Riding Mountain Park	756	50,42	99,41
Rossburn	590	50,40	100,48
Russell	560	50,47	101,16
Steep Rock	253	51,37	98,48
Strathclair	581	50,24	100,24
Swan River	340	52,06	101,16
The Pas	272	53,58	101,06
Yorkton A.	504	51,16	102,28

Group 25

Arran	450	51,58	101,44
Brandon A.	408	49,55	99,57
Camp Shilo & Shilo	382	49,49	99,39
Cypress River	376	49,33	99,05
Deerwood	338	49,24	98,19
Eriksdale	267	50,52	98,10
Gimli A.	221	50,38	97,03
Grass River	270	50,31	98,58
Graysville	283	49,30	98,10
Morden CDA	302	49,11	98,05
Neepawa CSC-AWN	369	50,14	99,28
Portage la Prairie A.	264	49,54	98,16
Rennie	322	49,51	95,32
Rivers A.	473	50,01	100,19
Stonewall	251	50,07	97,20
Winnipeg Int. A.	240	49,54	97,14

Group 26

Emerson	241	49,00	97,12
Emo	337	48,38	93,48
Indian Bay	327	49,37	95,12
Kenora A.	410	49,48	94,22
Sprague	327	49,02	95,38

* These stations were included in these groups in the grouping procedure, but were considered to represent local climates and were mapped with other surrounding or adjacent groups.

APPENDIX B. Comparative climatic boundary groups and associated significant variables with means and standard deviation values. (Significance of between-group variables was determined by Student t-test and established at the 95% confidence level.)

Groups	Variables	Means	Standard Deviations
1 and 4	May Temp.[1]	9.3/-2.2	0.4/1.2
	Elevation[2]	588/1014	198/172
	July Ppt.[3]	65.3/93.2	10.2/15.9
	Aug. Ppt.[3]	49.8/87.1	8.8/12.2
	Aug. Def.[4]	51.8/15.7	6.7/10.2
1 and 6	Elevation[2]	588/875	198/271
	July Temp.[1]	15.7/14.2	1.1/1.1
	Aug. Ppt.[3]	49.8/79.0	8.8/11.4
	Aug. Def.[4]	51.8/19.8	6.7/10.2
1 and 7	May > -2.2[5]	27.5/20.1	2.0/2.4
	May Temp.[1]	9.3/5.2	0.4/1.1
	Elevation[2]	588/211	198/61
1 and 9	May > -2.2[5]	27.5/21.7	2.0/4.5
	May Temp.[1]	9.3/6.3	0.4/1.9
	Elevation[2]	588/370	198/239
1 and 11	May > -2.2[5]	27.5/23.5	2.0/2.8
	May Temp.[1]	9.3/6.6	0.4/1.7
	July Temp.[1]	15.7/14.0	0.6/1.1
1 and 14	May Temp.[1]	9.3/8.3	0.4/0.7
	Elevation[2]	588/887	198/182
	July Ppt.[3]	65.3/116.1	10.2/11.9
	Aug. Def.[4]	51.8/8.6	6.7/9.1
1 and 15	May > -2.2[5]	27.5/24.6	2.0/2.0
	May Temp.[1]	9.3/6.7	0.4/1.4
	July Ppt.[3]	65.3/91.7	10.4/16.1
1 and 21	May > -2.2[5]	27.5/20.6	2.0/0.4
	May Temp.[1]	9.3/5.4	0.4/0.6
	July Temp.[1]	15.7/14.1	0.6/0.1
	Aug. Def.[4]	51.8/4.1	6.7/4.4

2 and 5	May Temp.[1]	8.9/9.7	1.4/0.2
	July Temp.[2]	15.6/16.9	0.8/0.8
2 and 6	Elevation[2]	638/875	91/271
	July Temp.[1]	15.6/14.2	0.8/1.0
2 and 13	May Temp.[1]	8.9/5.6	1.4/2.0
	Elevation[2]	638/1320	91/214
	Aug. Ppt.[3]	59.2/98.6	10.2/11.9
	Aug. Def.[4]	31.0/3.1	17.5/5.6
2 and 14	July Ppt.[3]	81.3/116.1	13.4/11.9
	Aug. Def.[4]	31.0/8.6	17.6/9.2
2 and 15	May Temp.[1]	8.9/6.7	1.4/1.4
	July Temp.[1]	15.6/14.5	0.8/1.6
2 and 25	July Temp.[1]	15.6/19.1	0.8/0.4
3 and 12	May > -2.2[5]	24.4/15.5	3.4/1.8
	May Temp.[1]	7.5/3.2	1.3/1.3
3 and 17	May > -2.2[5]	24.4/11.8	3.4/2.2
	May Temp.[1]	7.5/-2.5	1.3/1.1
	June > -2.2[5]	29.2/23.6	1.0/3.4
	Elevation[2]	1340/1918	143/643
	July Temp.[1]	14.8/11.5	1.5/2.8
	Aug. Def.[4]	42.9/24.9	23.0/11.9
	May Ppt.[3]	72.9/47.0	8.8/27.0
4 and 6	Sept. Ppt.[3]	67.3/38.4	11.9/5.6
4 and 10	May > -2.2[5]	28.0/12.7	2.2/3.2
	May Temp.[1]	7.8/0.1	1.1/4.7
	Elevation[2]	1014/1768	172/317
	July Temp.[1]	14.1/10.1	0.9/1.5
4 and 13	May > -2.2[5]	28.0/23.7	2.2/3.2
	May Temp.[1]	7.8/5.6	1.1/2.0
	Elevation[2]	1014/1320	172/214
	July Ppt.[3]	93.2/115.1	15.9/10.5
5 and 15	May > -2.2[5]	26.5/24.6	1.9/1.9
	May Temp.[1]	9.7/6.7	0.7/1.4
	July Temp.[2]	16.9/14.5	0.8/1.6
	Aug. Def.[4]	49.0/23.9	34.4/17.6

5 and 16	July Temp.[1]	16.9/13.6	0.8/1.4
5 and 19	May Temp.[1]	9.7/8.7	0.7/0.9
	Elevation[2]	568/454	113/133
5 and 22	May Temp.[1]	9.7/8.6	0.7/1.3
	July Temp.[1]	16.9/11.7	0.8/1.9
5 and 24	May > -2.2[5]	26.5/25.2	1.9/1.6
6 and 10	May > -2.2[5]	26.4/12.7	1.6/3.2
	May Temp.[1]	8.3/0.1	0.8/4.7
	June > -2.2[5]	29.7/25.4	0.3/1.9
	Elevation[2]	875/1768	271/317
	July Temp.[1]	14.2/10.1	1.0/1.5
6 and 13	May Temp.[1]	8.3/5.6	0.8/2.0
	Elevation[2]	875/1320	271/214
	Aug. Def.[4]	20.1/3.1	10.2/5.6
6 and 18	May Temp.[1]	8.3/5.8	0.8/1.9
	Sept. Ppt.[3]	38.4/77.0	5.7/17.8
7 and 9	May Temp.[1]	5.2/6.3	1.1/1.9
7 and 15	May > -2.2[5]	20.1/24.6	2.4/1.9
	Elevation[2]	211/677	61/104
	July Ppt.[3]	49.8/91.7	3.6/10.2
	May Ppt.[3]	18.8/39.6	5.1/4.4
7 and 21	July Temp.[1]	15.7/14.1	0.5/0.1
	July Ppt.[3]	49.8/101.6	3.6/32.3
	Aug. Def.[4]	58.7/3.0	18.3/4.4
8 and 10	May > -2.2[5]	20.1/12.7	3.2/3.2
	June > -2.2[5]	28.6/25.4	0.7/1.9
8 and 12	July Ppt.[3]	61.7/110.7	18.7/11.6
8 and 14	May > -2.2[5]	20.1/27.0	3.2/1.4
	May Temp.[1]	4.2/8.3	2.3/0.7
	Elevation[2]	1550/887	331/182
	July Temp.[1]	11.6/14.8	1.2/0.5
9 and 11	Elevation[2]	370/773	239/209
	July Temp.[1]	15.7/14.1	1.1/1.1
	Sept. Ppt.[3]	63.5/39.4	7.2/3.6

9 and 15	May > -2.2[5]	21.7/24.6	4.5/1.9
	Elevation[2]	370/677	239/104
	July Temp.[1]	15.7/14.5	1.1/1.6
9 and 16	May Temp.[1]	6.3/3.3	1.9/1.6
	Elevation[2]	370/700	239/247
	July Temp.[1]	15.7/13.6	1.1/1.4
9 and 20	June > -2.2[5]	29.5/27.4	0.4/1.8
	July > -2.2[5]	30.9/27.7	0.2/1.0
9 and 24	May > -2.2[5]	21.7/25.2	4.5/1.6
	Map Temp.[1]	6.3/8.4	1.9/1.0
10 and 12	July Temp.[1]	10.1/12.9	1.5/0.5
	July Ppt.[3]	95.3/61.7	21.6/18.7
10 and 13	May > -2.2[5]	12.7/23.7	3.2/3.2
	May Temp.[1]	0.1/5.6	4.7/2.0
	June > -2.2[5]	25.4/29.5	1.9/0.5
	Elevation[2]	1768/1320	317/214
	July Temp.[1]	10.1/13.4	1.5/0.7
	July Ppt.[3]	95.3/115.1	21.6/10.4
	Aug. Ppt.[3]	72.9/98.6	20.3/11.9
10 and 14	May > -2.2[5]	12.7/27.0	3.2/1.4
	May Temp.[1]	0.1/8.3	4.7/0.7
	Elevation[2]	1768/887	317/182
	July Temp.[1]	10.1/14.8	1.5/0.5
	July Ppt.[3]	95.3/116.1	21.6/11.9
10 and 19	May > -2.2[5]	12.7/25.3	3.2/2.0
	May Temp.[1]	0.1/8.7	4.7/0.9
	June > -2.2[5]	25.4/28.8	1.9/0.9
	Elevation[2]	1768/454	317/133
	July Temp.[1]	10.1/16.7	1.5/1.0
	July Ppt.[3]	95.3/65.5	21.6/9.2
	Aug. Def.[4]	10.4/46.7	15.2/12.2
11 and 15	July Ppt.[3]	69.6/91.4	13.7/10.2
	Aug. Def.[4]	47.0/23.9	16.7/17.6
11 and 16	May > -2.2[5]	23.5/20.0	2.8/0.5
	May Temp.[1]	6.6/3.3	1.7/1.6
	July Ppt.[3]	69.6/94.0	13.7/4.4
	Aug. Ppt.[3]	44.5/71.1	10.8/7.6
	Aug. Def.[4]	47.0/14.5	16.7/9.2

13 and 14	May > -2.2[5]	23.7/27.0	3.2/1.4
	May Temp.[1]	5.6/8.3	2.0/0.7
	Elevation[2]	1320/887	214/182
	July Temp.[1]	13.4/14.8	0.7/0.5
14 and 15	May > -2.2[5]	27.0/24.6	1.4/1.9
	May Temp.[1]	8.3/6.7	0.7/1.4
	Elevation[2]	887/677	182/104
14 and 16	May > -2.2[5]	27.0/20.0	1.4/0.5
	May Temp.[1]	8.3/3.3	0.7/1.6
14 and 18	May > -2.2[5]	27.0/23.4	1.4/2.7
	May Temp.[1]	8.3/5.8	0.7/1.9
15 and 16	May > -2.2[5]	24.6/20.0	1.9/0.5
	May Temp.[1]	6.7/3.3	1.4/1.6
15 and 18	Sept. Ppt.[3]	55.4/77.0	5.1/17.8
15 and 19	May Temp.[1]	6.7/8.7	1.4/0.9
	July Temp.[1]	14.5/16.7	1.6/1.0
	Aug. Def.[4]	23.9/46.7	17.6/12.2
15 and 22	July Temp.[1]	14.5/11.7	1.6/1.9
15 and 24	May Temp.[1]	6.7/8.4	1.4/1.0
	Elevation[2]	677/436	104/49
	July Temp.[1]	14.5/17.1	1.6/1.1
19 and 20	May > -2.2[5]	25.3/20.8	2.0/2.1
	May Temp.[1]	8.7/6.3	0.9/1.4
	Elevation[2]	454/274	133/40
	July Temp.[1]	16.7/14.4	1.0/1.2
19 and 23	Elevation[2]	454/262	133/42
	July Temp.[1]	16.7/18.7	1.0/0.5
	May Ppt.[3]	41.4/69.9	10.5/8.0
19 and 24	June > -2.2[5]	28.8/29.7	0.9/0.4
19 and 25	May > -2.2[5]	25.3/27.2	2.0/0.7
	May Temp.[1]	8.7/9.8	0.9/0.3
	Elevation[2]	454/325	133/72
	July Temp.[1]	16.7/19.1	1.0/0.4

20 and 23	May > -2.2[5]	20.8/26.5	2.1/1.1
	May Temp.[1]	6.3/9.2	1.4/0.8
	June > -2.2[5]	27.4/29.6	1.8/0.5
	July Temp.[1]	14.4/18.7	1.2/0.5
	May Ppt.[3]	35.6/69.9	13.2/8.0
20 and 24	May > -2.2[5]	20.8/25.2	2.1/1.6
	May Temp.[1]	6.3/9.5	1.4/1.0
	July Temp.[1]	14.4/17.1	1.2/1.1
	July > -2.2[5]	27.7/30.7	1.0/0.5
23 and 25	Elevation[2]	262/325	42/72
	June Def.[4]	2.5/9.1	3.6/2.5
23 and 26	Elevation[2]	262/328	42/60
	July Ppt.[3]	80.8/110.7	7.2/26.0
25 and 26	July Ppt.[3]	83.3/110.7	14.1/26.0
	Aug. Def.[4]	42.7/24.6	7.6/16.3
	Sept. Ppt.[3]	40.9/68.6	4.4/9.5

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[1] Mean Temperature (°C)

[2] Elevation above sea level (m)

[3] Total Precipitation (mm)

[4] Water Deficiency (mm)

[5] Number of days with minimum temperature greater than -2.2°C