Climatological Bulletin

Volume 17, Number 1, April 1983

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Information for Contributors

As a publication of the Canadian Meteorological and Oceanographic Society, the Climatological Bulletin provides a medium of information on climatology. The editorial board gives special encouragement to the submission of manuscripts on applied climatology, e.g., agriculture, climatic change and variability, climate impact assessment, data bases, energy, environment, forestry, health, measurement, recreation, and transportation. Several formats are provided, including the formally reviewed "Research Articles", and the less formal "Notes" section. The latter consists of shorter contributions, such as research notes, surveys, overviews, and book reviews. Submissions from students through their professors are encouraged. News items are welcome, and are placed in a separate "News" section.

Authors, including students, may choose to submit their manuscripts to formal review, or Notes. This should be indicated in the cover letter accompanying the manuscript. Research articles are independently reviewed by at least two anonymous referees. Notes are reviewed by the editor in consultation with the editorial board. Articles are accepted in either English or French.

Contributors should submit manuscripts to Stewart J. Cohen, Editor, Climatological Bulletin, Dept. of Geography, York University, 4700 Keele Street, Downsview, Ontario, Canada, M3J 1P3. All manuscripts should be typed double spaced on one side of good quality white paper, 28 cm × 21.5 cm or its nearest equivalent. The abstract, list of references, tables, and a list of figure captions should be typed double spaced on separate sheets. The total length of research manuscripts should not exceed 5,000 words, exclusive of illustrative material. Comments, reviews, opinions, and news items should not exceed 1,500 words. Furnish an original and three copies if possible, in the order listed below.

TITLE PAGE should include the full names of authors, and professional affiliations.

The ABSTRACT should be less than 250 words, and typed on a separate page.

The TEXT of longer contributions should be typed double spaced on numbered pages, and divided into sections, each with a separate heading and numbered consecutively. The section heading should be typed on a separate line.

ACKNOWLEDGEMENTS are typed on a separate sheet immediately following the text.

If FOOTNOTES are required, they should be typed, double spaced, on a separate sheet under the heading "Notes" at the end of the text.

REFERENCES should be arranged alphabetically by senior author's last name. The text citation should consist of name(s) of the author(s) and the year of publication, for example Jones (1975) or (Jones, 1975). When there are two or more cited publications by the same author in the same year, distinguishing letters a, b, etc., should be added to the year. A reference to "in press" implies that the paper has been accepted for publication. Titles of periodicals should be given in full.

FIGURE LEGENDS must be provided for each figure, and should be typed together, double spaced, on a separate sheet.

ILLUSTRATIONS should be numbered sequentially. Original drawings, lettering, and symbols should be large enough so that after reduction, the smallest character will be at least 1.5 mm high.

Each TABLE should be numbered sequentially. Type all tables double spaced on separate sheets.

Authors should use the International System of units, but may show other units in parentheses. Authors should provide instructions in the margin for any special type required (Greek letters, capitals, bold face, etc.).

Climatological Bulletin

Vol. 17, No. 1, April 1983

Foreword

This issue marks the beginning of a new era for the Climatological Bulletin as a publication of the Canadian Meteorological and Oceanographic Society (CMOS). The Bulletin was formerly published by the Department of Geography at McGill University in Montreal. The series of events that led to this changeover has been outlined by the former editor and founding father of this periodical, B.J. Garnier, in issue no. 32.

Editorial policy is designed with a view towards establishing the Bulletin as a Canadian publication on climatology, with a nationwide scope. As such, a system for reviewing manuscripts has been instituted, as outlined in Information for Contributors, printed in this and subsequent issues. The two-tiered system places the Bulletin at an intermediate level of review, between the other CMOS publications, Atmosphere-Ocean and Chinook. We hope that by publishing both formally reviewed research articles, and less formal notes and surveys, as well as student contributions, the Bulletin will be able to provide information of interest to a broad spectrum of readers.

An endeavour such as this could not have been undertaken successfully without considerable support from the interim editorial board, particularly Ben Garnier and David Phillips. The efforts of the publications committee of CMOS are gratefully acknowledged.

Stewart J. Cohen

An Application of Principal Component Analysis and an Agroclimatic Resource Index to Ecological Land Classification for Alberta

G.D.V. Williams and *J.M. Masterton*

The assessment of the suitability for alternative uses of land requires as a first step the description and evaluation of land's intrinsic worth. Ecological land classification (ELC) is a process used to obtain this appraisal. The identification and delineation of ecoregions requires an awareness of weather and climate characteristics. In past classifications of land, climate has often been only inferred indirectly through vegetation. The objectives of the present study were to determine if existing ecoregions are climatically distinct and, more generally, to explore possible techniques of incorporating climate more directly into the ELC process.

The study area was the province of Alberta. Spatial climatic analysis procedures were used to obtain a more uniform geographical representation of the province than could be provided by climatological stations. Using these procedures, values were generated for each of 98 climatic variables for each of 110 grid points in Alberta. Two methods of analysis were then applied to these generated climatic data. The first involved the use of a principal component analysis (PCA). The second applied Turc's climatic index of agricultural potential. A considerable degree of climatic uniqueness in the various ecoregions, as assessed by these two methods, was confirmed using analysis of variance techniques.

Turc's index appears biased toward growing season conditions while PCA, as applied here, perhaps overemphasized winter temperature characteristics. However, the results leave no doubt that the procedures used in this study can provide very useful climatically based information for ecological land classification.

INTRODUCTION

Attempts to assess the inherent value of land to provide information for land use planning purposes have led to the development of an integrated method of appraisal, the ecological land survey. Scales of such surveys range from the macro- or ecoprovince scale covering hundreds of thousands of square kilometres, through ecoregions, ecodistricts, ecosections and ecosites to the ecoelement or most detailed level encompassing perhaps only a few square metres (Wiken, 1980).

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Climate is obviously a major factor controlling biological activity but it is seldom directly assessed in the ecological land survey process. Instead, climate is largely inferred from vegetative and soil patterns. Most of the ecological land classification (ELC) work has been done at relatively detailed scales. The climatological stations by themselves are particularly inadequate for representing the climate at these scales (Williams, McKenzie and Sheppard, 1980), while the patterns of the other elements studied in ecological land surveys to some extent reflect the meso- and microclimatic patterns.

Even at the macroscale, the available climatological station data are not sufficiently representative. Ouellet (1969) has documented the bias of Canadian climatological stations toward low latitude and altitude and consequent limitations in zonation studies. Methods have been developed to spatially resolve climatic data using combinations of climatic and other geographic information (Hopkins, 1965, 1968; Solomon et al, 1968). These are applicable at an ecoregion scale (map scale 1:1 million to 1:3 million) but they have not been applied by climatologists to ecological land classification problems.

A project was therefore initiated within the Canadian Climate Centre to:

1 develop and demonstrate ways to generate climatic data of particular relevance to ecological land classification,
2 illustrate how these climatic data can be transformed or rendered suitable for incorporation into the process of ecological land classification, and
3 demonstrate the usefulness of the techniques developed by employing them to assess the bioclimatic distinctiveness of ecoregions that had previously been delineated without benefit of systematically incorporated climatic data.

Because of the variety of climates in Alberta and the availability of ELC information and other relevant data, the decision was made to begin with a pilot study for that province. Methods developed in this work should be applicable for other parts of Canada.

In a study of this kind, it is necessary both to apply criteria relating ecoregion to climate, and to express the relationships over a large geographical area. Because so little work has been done on the application of climatology to ecological land classification, we wanted to use two different sets of procedures for relating ecoregion to climate, to provide a basis for comparison. One procedure was principal component analysis (PCA), which was employed to derive a generalized, relatively objective climatic classification based upon climatic data alone, without direct reference to such external factors as vegetation or soils. The other procedure involved the use of Turc's climatic index of agricultural potential (CA) (Turc and Lecerf, 1972). This is a more traditional approach than PCA in that it attempts to combine a number of elements considered to be important into a single index, using subjectively derived formulae. Turc's index (CA) is of particular interest to the present study because the evaluation of land for agriculture is an important application of ecological land classification. Also, CA is probably almost as applicable for forestry and the growth of natural vegetation in general as for agriculture, because the factors used in it incorporate heat, moisture availability and light, the main controls of most life processes.

For this pilot project it was desirable to demonstrate methods for geographically expressing the data that were relatively objective and would lend themselves to subsequent applications involving much higher spatial resolution and larger quantities of data. For this purpose a spatial climatic estimation approach involving the use of equations (Williams, McKenzie and Sheppard, 1980) was considered to be the most appropriate and was therefore used for those variables for which equations were available.

A latitude-longitude grid having a one-degree spacing produces 110 points for estimation in Alberta (Figure 1). The spatial climatic estimates were made for each of these points. The derived climatic values for the 110 points were employed both in PCA and in computing CA, and the results were then analysed in relation to ELC data for Alberta.

DERIVING THE CLIMATIC DATA

Hopkins (1968) provided equations for the estimation of monthly temperature normals for the 1931-1960 period from latitude, longitude and altitude on the Canadian Great Plains. These equations included cubic and quartic terms, but it was found that the simpler equations which he had provided in an earlier memorandum (1965) produced considerably more realistic results so these earlier equations were used in the present work. They are of the form:

$$T = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + a_7x_1x_2 + a_8x_1x_3 + a_9x_2x_3$$

where the x values are latitude, longitude and altitude terms and the a's are regression coefficients. There is one set of the coefficients for each of: normal mean daily maximum, minimum and mean temperature for each month of the year. Hopkins had also provided equations for estimating the standard deviation of monthly mean temperatures.

A square grid regression analysis system for estimating climatic normals (Solomon et al, 1968) was used by the Shawinigan Engineering Company in 1970 to generate estimates of monthly precipitation normals for 10-km grid squares covering the Prairie Provinces. Their system took into account factors such as altitude, distance from mountain barriers, etc. for the squares in which the stations were located, and then applied the equations to generate normals for all the grid squares. For each of our 110 points we used the estimated precipitation normals for the 10-km grid square containing the point, except that data for the grid squares with southern edges south of the 49th parallel were unavailable, so the next squares to the north were used in those cases.

The accuracy of the spatial climatic models with which the temperature and precipitation normals were generated has been discussed by their originators (Hopkins, 1965, 1968; Solomon et al, 1968). The present authors from their own work in applying these models believe that in about 9 cases out of 10, the estimated monthly temperature normals would be within 2°C of actual normals. The estimated precipitation normals also seemed to give realistic results in several applications. These and the other climatic variables used in the analysis are listed in Table 1. It should be kept in mind that both the Hopkins equations and the Shawinigan data will not be too satisfactory in the Cordilleran region of the province as these procedures were based on analyses of Canadian Great Plains data.

PRINCIPAL COMPONENT ANALYSIS

The procedures involved in the principal component analysis as used here are outlined in Figure 2. Quantitative explanations of principal component analysis are provided in detail in many texts (Hotelling, 1935; Catell, 1952; Rummel, 1968; King, 1969; Mather and Doornkamp, 1970; Van de Geer, 1971). We note only that principal component analysis studies the data structure from the viewpoint of differences, and ought to be considered a first stage in factor analysis (PCA being one form of factor analysis). PCA is often used when no model assumptions have been made. Factor analysis can later be added to test assumptions. Hence the choice of PCA over factor analysis seems appropriate in this application.

The use of principal component analysis or factor analysis in climatology is not new. Steiner (1965), Benson and Johnson (1970), Nicholson and Bryant (1972), McBoyle (1971, 1972), and Kojima (1973) have all derived climatic classifications using one or other of these techniques. Miller and Auclair (1974) were concerned more directly with a climatic classification of Canadian forest regions while Powell and MacIver (1977) narrowed their area of interest to the forested regions of the Prairie Provinces. Paterson, Goodchild and Boyd (1978) dealt with selecting environments in Australia for sampling purposes, while Gadgil and Joshi (1980) applied a principal component analysis to the mapping of the climate of India using precipitation data alone.

One criticism of many earlier climatic classifications is that they were based upon predetermined, often subjectively chosen criteria which pertained to vegetation or some other indirect indicator of climate. Identical results were often unobtainable when such techniques were employed independently by different scientists. Principal component analysis tends to be much more objective in nature and, while it is recognized that no statistical technique can be said

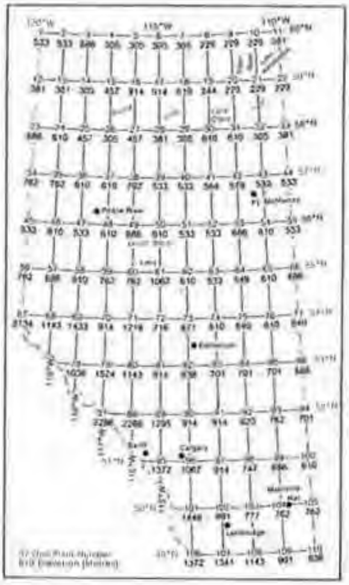

FIGURE 1   One degree interval grid points and their elevations

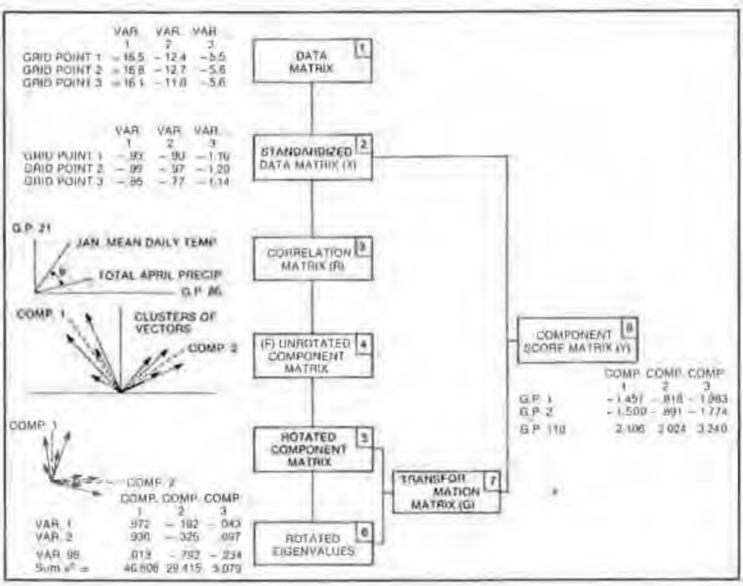

FIGURE 2   Flow chart for principal component analysis

TABLE 1 Climatic variables used in principal component analysis

Element Number	Element Name		Source
1-12	Normal Mean Daily Maximum Temperature	January through December	Estimated from latitude, longitude, & elevation using Hopkins' model (1965)
13-24	Normal Mean Daily Minimum Temperature	January through December	Hopkins (1965)
25-36	Normal Mean Daily Temperature	January through December	Hopkins (1965)
37-48	Standard Deviation of Mean Temperature	January through December	Hopkins (1965)
49	Normal Annual Degree-days Above 5 C		Estimated from monthly mean temperature normals and standard deviations (Holmes and Robertson, 1959)
50	Normal Annual Degree-days Below 0 C		Holmes and Robertson (1959)
51-62	Normal Total Precipitation	January through December	Estimated from many geographic variables using Solomon's (1966) model
63-70	Normal Total Potential Evapotranspiration	March through October	Estimated from normal mean daily maximum and minimum temperatures using latent evaporation equation of Baier & Robertson (1965)
71-82	Mean Daily Photoperiod (Day Length)	January through December	Abstracted from table (Russelo, Edey & Godfrey, 1974)
83	Normal Last Spring Frost Date		Estimated from normal temperatures using model of Sly, Robertson & Coligado (1971)
84	Normal Frost-free Duration		Sly, Robertson & Coligado (1971)
85-96	Normal Mean Daily Global Radiation	January through December	Abstracted from maps (Phillips and Aston, 1980)
97	Normal Annual Snowfall		Abstracted from map (Canada Department of Transport, 1968)
98	Normal Last Day with Snow Cover		Abstracted from map (Masterton et al, 1976)

to be completely objective (Johnston, 1968), the selection of variables used and the definition of 'significant' tend to be the only areas where the user can incorporate subjectively based decisions.

Fourteen elements were chosen to reflect relevant aspects of Alberta's climate. Where possible, monthly mean values were provided because of the intention to examine generalized climate relationships. This resulted in the input of 98 variables for each of the 110 grid points into the principal component analysis (see Table 1). The application of PCA to regularly spaced control points has not been done in previous studies as far as is known to the authors, but it was proposed by Steiner (1965) who recognized the problems associated with an irregular placement of control points, such as would occur if only meteorological stations were used.

The dimensions of the correlation matrix derived here, 98 by 98, prevent its inclusion with this text.

Without any imposed cutoff criteria, performing principal component analysis on the correlation matrix results in 98 components being derived, in order of decreasing variance explanation. The first seven components have eigenvalues equal to or greater than 1.00. These seven components provide 96.6% of the variance explanation. A Varimax rotation (Kaiser, 1958) was carried out, to simplify the component matrix and facilitate the identification and explanation of components. Following rotation, the first two components provide over 77% of the variance explanation (Table 2). The greater magnitude for eigenvalue 5 than for eigenvalues 3 and 4 is a function of the process of rotation.

The component matrix (Table 3) identifies which of the original 98 variables are most important to the individual components. The rotated component matrix (only the first seven components were rotated) is presented in Table 3. Convention among users of PCA and factor analysis (e.g. McBoyle, 1971, 1972) has loadings equal to or greater than plus or minus 0.7 being identified as 'significant', and this convention is followed here. Those variables with loadings beyond the plus or minus 0.70 limits are marked (*) in Table 3 for each of the components. Note that in Component 7 there are no 'significant' loadings, so effectively we have ignored the 7th component from this point on. Loadings for Components 1 and 2 are graphed in Figure 3. Note that in Figure 3, mean daily maximum and minimum temperature loadings are omitted because their patterns are quite similar to those displayed by daily mean temperature loadings.

The first component (Tables 2 and 3 and Figure 3) contains high loadings for many of the elements which are prominent during mild winter conditions such as those which occur with the frequent invasion of chinook winds in the southern regions of the province. High values are associated with all of the measures of temperature from October through March or April. Relatively few degree-days below 0°C also suggest mild winters. In southern Alberta in the summer, the days are shorter than they are in the north. In winter, southern Alberta's days are longer than they are in the north. Thus, the negative loadings

TABLE 2 Results of principal component analysis after rotation

	COMP. 1	COMP. 2	COMP. 3	COMP. 4
Eigenvalues	46.6077	29.4149	5.0968	3.5161
% Variance Explained	47.5589	30.0152	5.2008	3.5879
Cum % Variance Exp	47.5589	77.5741	82.7749	86.3628
Cum % Common Var Exp	49.2299	80.2996	85.6382	89.3971
	COMP. 5	**COMP. 6**	**COMP. 7**	**SUMMATION**
Eigenvalues	5.3712	2.6500	2.0169	94.6736
% Variance Explained	5.4808	2.7041	2.0581	96.6058
Cum % Variance Exp	91.8436	94.5477	96.6058	-
Cum % Common Var Exp	95.0705	97.8696	100.0000	-

TABLE 3 Rotated component matrix of loadings

VARIABLE	COMP 1	COMP 2	COMP 3	COMP 4	COMP 5	COMP 6	COMP 7
Max							
1 Jan	.9715*	-.1921	-.0431	.0563	.0381	-.0865	.0525
2 Feb	.9300*	-.3252	-.0970	.0274	.1073	-.0350	.0599
3 Mar	.9557*	-.1234	-.1697	-.0210	.1653	-.0220	.0688
4 Apr	.6398	.7325*	-.1615	-.0877	-.1046	.0114	-.0505
5 May	.4533	.8264*	-.1261	-.1846	.0825	.0564	-.1279
6 Jun	.0738	.9817*	-.0246	-.1140	-.0195	-.0350	-.0687
7 Jul	.1649	.9558*	.1574	-.0202	-.1407	-.1029	-.0220
8 Aug	.2733	.9349*	.1708	-.0445	-.0762	-.1041	-.0305
9 Sep	.5847	.7933*	.0406	-.0798	-.1041	-.0519	-.0540
10 Oct	.7322*	.6401	-.0197	-.0588	-.2150	-.0194	-.0408
11 Nov	.9293*	.2823	-.0275	.0007	-.2241	-.0215	.0300
12 Dec	.8249*	.3875	-.0463	.0635	-.3782	-.0995	.0364
Minimum							
13 Jan	.9771*	.0227	-.1322	.0879	.0098	-.0593	.0203
14 Feb	.9423*	-.2372	-.1246	.0450	.1811	-.0448	.0788
15 Mar	.9599*	.1861	-.2010	-.0116	-.0182	-.0194	-.0082
16 Apr	.8167*	.5082	-.2222	-.0701	.0708	.0918	-.0541
17 May	.4719	.8314*	-.1683	-.1042	.1721	.0373	-.0127
18 Jun	.0313	.9810*	-.0675	-.0354	-.1556	-.0512	.0054
19 Jul	-.0809	.9756*	.0655	-.0180	-.1671	-.0473	.0192
20 Aug	-.0608	.9740*	.0720	-.0148	-.1725	-.0555	.0380
21 Sep	.1062	.9574*	-.0009	.0159	-.2204	-.0402	.0650
22 Oct	.8460*	.1382	.0311	.0303	.4413	-.0532	.1862
23 Nov	.9674*	.1817	-.0982	.0447	-.0210	.0090	.0639
24 Dec	.9152*	.3039	-.0920	.0770	-.1963	-.0597	.0250
Mean							
25 Jan	.9831*	-.0795	-.0911	.0739	.0159	-.0755	.0369
26 Feb	.9379*	-.2819	-.1201	.0388	.1396	-.0427	.0454
27 Mar	.9733*	.0461	-.2026	-.0154	.0669	-.0209	.0262
28 Apr	.7486*	.6219	-.1842	-.0845	-.0217	.0630	-.0569
29 May	.5524	.7715*	-.1400	-.1569	.1404	.0913	-.0846
30 Jun	.0351	.9876*	-.0507	-.0694	-.0929	-.0498	-.0261
31 Jul	.0482	.9741*	.1156	-.0213	-.1589	-.0755	-.0031
32 Aug	.1229	.9699*	.1283	-.0335	-.1329	-.0742	.0038
33 Sep	.3636	.9120*	-.0033	-.0349	-.1734	-.0510	.0029
34 Oct	.8489*	.5233	.0099	-.0348	.0036	-.0214	.0286
35 Nov	.9522*	.2382	-.0612	.0278	-.1460	-.0327	.0535
36 Dec	.8765*	.3520	-.0656	.0656	-.2892	-.0718	.0291
Std. Dev.							
37 Jan	.2979	.5912	-.2622	-.0916	-.6530	.0072	-.0057
38 Feb	-.1633	.7816*	-.0351	-.1040	-.5551	-.0064	-.0314
39 Mar	-.3108	.8077*	-.0042	-.0425	-.4887	.0101	-.0720
40 Apr	-.6437	-.6103	.0002	-.0667	.3282	.2615	.0176
41 May	.2109	-.0477	.8739*	-.0189	.2525	-.3108	.0409
42 Jun	.0122	-.5412	.5713	.0008	.5334	-.2448	.0867
43 Jul	.4440	-.4992	.3099	-.0370	.6507	-.1091	-.0223
44 Aug	-.6959	-.5979	.1808	.0761	-.1242	-.2431	.1005
45 Sep	.3206	-.5279	.0651	-.0640	.7636*	.0019	-.0483
46 Oct	.2373	-.7607*	.1453	.0186	.5709	-.0157	.0761

VARIABLE	COMP 1	COMP 2	COMP 3	COMP 4	COMP 5	COMP 6	COMP 7
47 Nov	-.2454	.5245	-.4332	-.0874	-.6608	.0936	-.0583
48 Dec	-.4716	-.4244	-.5818	-.2197	-.0913	.3323	.0005
Deg.Days >5C							
49	.3176	.9177*	.0098	-.0583	-.1927	-.0712	.0358
Deg.Days <0C							
50	-.9896*	-.0601	.1024	-.0401	-.0171	.0303	-.0063
Precip.							
51 Jan	.1826	-.7139*	-.2820	.1734	.1770	-.1419	.4618
52 Feb	.3449	-.5763	-.0181	.5213	.2543	.0177	.4028
53 Mar	-.1496	-.5571	.3098	.4987	.0755	-.0079	.4788
54 Apr	.6678	-.0767	.2560	.6477	.0395	-.1702	-.0740
55 May	.8331*	-.0194	.2168	.4591	.0440	.0480	-.0920
56 Jun	.8675*	.0973	-.0335	.2762	.0242	.2405	-.1610
57 Jul	-.0646	-.0400	-.2067	-.0501	-.0738	.8989*	-.1791
58 Aug	.1786	-.4606	-.0671	-.2486	-.0588	.6670	.3007
59 Sep	.1525	-.3820	.5872	.3283	.1628	.3591	.3894
60 Oct	-.4910	-.6169	.0855	.1088	.0038	-.1511	.5116
61 Nov	-.5065	-.4518	.1846	.3674	.0022	-.1271	.5545
62 Dec	-.2337	-.2860	.0017	.8015*	.0056	-.1735	.2558
PE							
63 Mar	.1637	-.6560	.0344	-.0393	.7119*	-.0305	.0199
64 Apr	.7014*	.6894	-.0324	-.1000	-.0422	-.0615	-.0492
65 May	.5469	.7467*	-.0542	-.2111	.0333	.0587	-.1900
66 Jun	.1882	.8980*	.0461	-.2132	.1663	-.0122	-.1603
67 Jul	.3838	.8756*	.2209	-.0211	-.1089	-.1339	-.0527
68 Aug	.6149	.7336*	.2357	-.0542	.0179	-.1142	-.0786
69 Sep	.8704*	.4373	.0965	-.1049	.0155	-.0402	-.1048
70 Oct	.6235	.4021	.3488	-.0533	.0414	-.4904	.0270
Photoperiod							
71 Jan	.9712*	.1191	.1414	-.0278	.0786	.0515	-.0615
72 Feb	.9714*	.1073	.1739	-.0289	.0821	.0246	-.0378
73 Mar	.7488*	.1372	-.0226	.1573	.0448	.1290	-.2415
74 Apr	-.9675*	-.1302	-.1409	.0262	-.0685	-.0299	.0581
75 May	-.9735*	-.1005	-.1502	.0405	-.0852	-.0691	.0433
76 Jun	-.9727*	-.1087	-.1423	.0324	-.0836	-.0657	.0551
77 Jul	-.9720*	-.1089	-.1550	.0216	-.0794	-.0401	.0552
78 Aug	-.9716*	-.1165	-.1634	.0137	-.0722	-.0225	.0504
79 Sep	-.9757*	-.1185	-.1501	.0139	-.0890	-.0219	.0496
80 Oct	.9601*	.1098	.1523	-.0186	.1071	.0297	-.0743
81 Nov	.9709*	.1120	.1482	-.0215	.0865	.0515	-.0665
82 Dec	.9731*	.1176	.1495	-.0326	.0753	.0493	-.0412
Spring frost							
83	.0242	-.8408*	.1246	-.1199	-.1503	-.0158	-.0004
Frost-free							
84	.1611	.7504*	-.0996	.0671	.5020	-.0351	.0600
Global radn.							
85 Jan	.9180*	.1968	.3044	-.0034	.0769	-.1200	-.0300
86 Feb	.9462*	.1383	.2234	-.1003	.0892	.0894	-.0326
87 Mar	.8488*	.2395	.3896	-.0951	.0928	.1225	-.0484
88 Apr	.5466	.4389	.6508	-.0581	.0384	.0391	-.0713
89 May	.7333*	.2883	.5835	-.0226	.0497	-.1409	-.0765
90 Jun	.8872*	.0925	.1891	-.0524	.0972	-.2056	.2416
91 Jul	.8940*	.1705	.3246	.0424	.0806	-.2172	-.0043
92 Aug	.9127*	.1780	.3279	-.0026	.0642	-.1334	.0787
93 Sep	.9786*	.1040	.1367	-.0127	.0664	.0063	-.0633
94 Oct	.9503*	.1179	.2127	-.0038	.0376	-.1292	-.0144
95 Nov	.9679*	.0894	.1504	-.0606	.0890	-.0515	.0125
96 Dec	.9334*	.1764	.2517	-.0657	.0724	.0246	-.1056
Snowfall							
97	.1687	-.2865	-.0746	.8622*	-.0496	.0284	-.0785
Last snow cover							
98	.0134	-.7920*	-.2336	.2924	.0310	-.1888	.1881

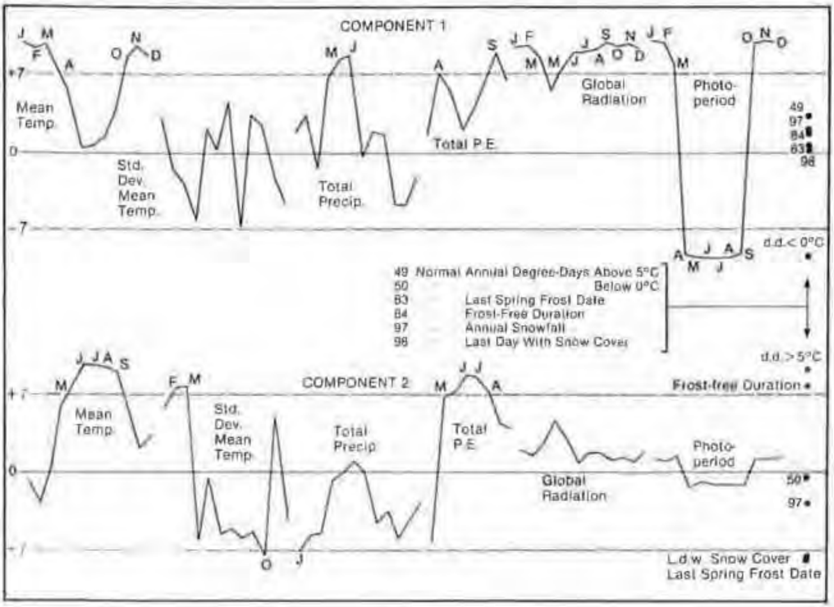

FIGURE 3 Loadings for components 1 and 2

for photoperiod from April through September and positive loadings from October through March are indicative of a southerly location. High loadings are also given to global radiation values throughout the year, to total precipitation in May and June, and to potential evapotranspiration in April and September. The conditions associated with Component 1 tend to result when a ridge of high pressure becomes stalled over the British Columbia-Alberta border in winter. Frigid Arctic air from the north is blocked and Alberta enjoys a relatively mild winter. The eventual movement of the storm tracks in the spring results in a period of above average precipitation in May and June. Thus, if one was to label the first component, 'mild winter' might seem appropriate.

The second component could be characterized as 'lengthy, relatively warm summers'. Component loadings are high for all measures of temperature from April or May through September, and for degree-days above 5°C. Loadings for the standard deviations of daily mean temperatures in February and March also tend to be high, reflecting the contribution to this component of early arrivals of warm spring weather, which are most likely where the temperatures for these months are most variable. The negative association with the standard deviation of the daily mean temperature in October suggests that the transition from summer to winter is relatively late. Also associated with the high summer temperatures are high PE values for May through August. The early arrival of warm weather in the spring is suggested by the negative loadings for the beginning of the frost-free season and the last day with snow cover. Below normal winter precipitation is implied by the negative loading for mean total precipitation in January.

Such summer weather is frequently associated with a situation in which a polar continental high that has been quasi-stationary over northern Canada moves south and continues to modify over the Prairies, where it typically gives hot dry summer days with occasional air mass thunderstorms and becomes diffuse, with weak pressure gradients. The resulting pressure patterns minimize the invasion into Alberta of cool, showery weather from the north or mild rainy conditions from the southwest. The warm, dry winds from southern Saskatchewan tend to predominate.

Components 3 through 6 display high loadings for only one or two variables. In Component 3, the standard deviation of daily mean temperature in May is represented by a high positive loading. This would seem to be indicative of a wide range of temperature conditions, as might occur during a transitional month from winter-spring to spring-summer. Component 5 describes a similar pattern for September temperatures, suggesting the transition from warm to cool conditions. Component 4, labelled 'heavy winter snowfall, is composed of high component loadings for both December precipitation and annual snowfall. Component 6 contains a high positive loading for July precipitation.

Various thermal aspects of climate are emphasized in four of the six components, and moisture is of primary consideration in the other two. This emphasis on temperature probably reflects realistic climatic characteristics in Alberta, but may also be indicative of the fact that 36 temperature variables were directly incorporated into the analysis, in addition to several variables derived from temperature, as compared with only 13 precipitation variables. Nevertheless, the components which were identified seem to reflect distinct climatic patterns, and the levels of explained variance provided would suggest considerable significance, especially for the first two components.

The final matrix of values provided by the principal component analysis presents the component scores. These quantify the strength of the relationship between each grid point and each of the six components. High positive values indicate that a given component plays a most significant role in the climate of a given location. High negative component scores suggest that the relative absence of climatic conditions represented by a component is also significant. Component scores near 0 identify a weaker presence or absence of the component's characteristics at a given location.

Component scores allow the mapping and spatial interpretation of individual components. Interpolation among the 110 grid points is not easy, especially in areas of high and variable elevation. All values for those points closest to the Rocky Mountains should therefore be viewed with extreme caution. The presentation of Components 1 and 2 in Figures 4 and 5 must be viewed as preliminary and indicative of only macroscale patterns.

Figure 4 illustrates the spatial variation of Component 1 which we have labelled 'mild winter'. The presence of mild winters is most strongly felt in southern Alberta and the absence is most significant in the northern part of the province. The spatial pattern not unexpectedly shows a strong latitudinal bias. Component scores in excess of 1.0 extend approximately from halfway between Edmonton and Calgary southward. In the north, component scores equal to or less than −1.10 extend from just south of Lake Claire to the Northwest Territories boundary.

Component 2 (Figure 5), 'lengthy, relatively warm summers' shows considerably more variation with topography. Positive values in southern Alberta exceed +1.5 while scores lower than −1.5 are identified only at high elevations in northern portion of the British Columbia-Alberta boundary (some below −4.0) should be ignored in the present study.

As Johnston (1968) has stated, factor analysis (and therefore PCA) does not classify – it merely rewrites the original data in a new form. The intent here was not to develop new theory concerning the climate of Alberta (the dangers of which have been exemplified by Armstrong, 1967), but merely to organize the climatic data in such a way as to facilitate their use for ecological land classification. Researchers have, in the past, taken a number of approaches toward the grouping of component scores, including heirarchical grouping and discriminant analysis (Powell and MacIver, 1977), cluster analysis (Miller and Auclair, 1974), the overlaying of maps of Factor 1 and Factor 2 (Paterson,

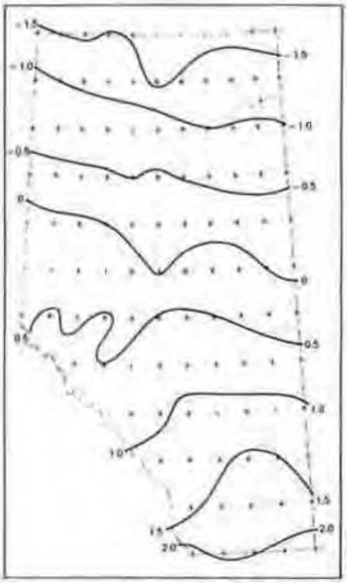

FIGURE 4 Component 1 scores

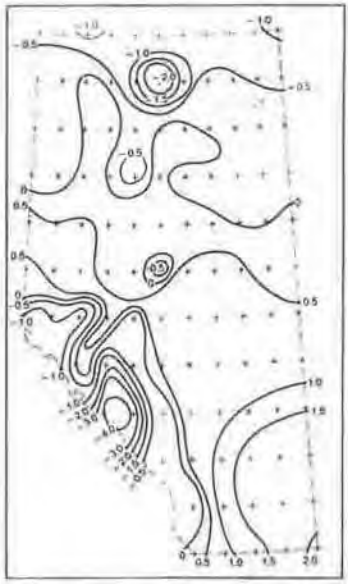

FIGURE 5 Component 2 scores

Goodchild and Boyd, 1978), nearest centroid clustering (Gadgil and Joshi, 1980), and the step-wise processing of a distance matrix (McBoyle, 1972).

Because of our purpose in relating climatic information to ecological land classification, the procedures used by other authors in grouping component scores were not adopted here. Scores for Components 1 and 2 for each of the 110 points were plotted on a two-dimensional graph (Figure 6). As the methods used here are most appropriate for macroscale applications, data relating to ecoregions were selected for comparative analysis. One source of such data for Alberta is the work of Strong and Leggat (1981). Their map was reviewed and the identifier of the ecoregion or subregion in which each of our sample points fell was abstracted (Figure 7). When their ecoregions and subregions were outlined on the graph (Figure 6), the patterns were largely discrete with very little overlap. Table 4 presents several component score statistics for each of the ecoregions and subregions. An analysis of variance was performed for each of the six components to test the groupings statistically (Table 5).

Visual examination of Figure 6 suggests that the first two components of the analysis, derived entirely from climatic statistics, are reflected in Strong and Leggat's ecoregion classification. Grid points with high positive component scores in both the 'mild winter' and 'lengthy, relatively warm summer' components are associated with the several grass ecoregions. Grid points with high negative component scores relate to northern and subarctic ecoregions. Points in the Boreal Mixwood ecoregion have low negative to low positive scores for both components, and points within the Aspen Parkland have moderate positive scores, reflecting the natural gradation of ecoregions.

The data for 110 points do not provide an adequate basis for detailed spatial comparisons of the components with Strong and Leggat's ecoregion mapping as the latter was done at a much finer scale. Nevertheless, event these 110 grid points provide sufficient detail to indicate how climate relates to their ecoregions.

For the three grid points in the Rocky Mountains (points 67, 87 and 88), extrapolation of the spatial climatic models to altitudes above those involved in their derivation was required. Thus, reliable results cannot be expected for these points. Nevertheless the first of these points, which is located in the Alpine ecoregion, is quite clearly distinguished by its very large negative Component 2 score, i.e. it is most marked by the absence of 'lengthy, relatively warm summers'. The second point, which is borderline between Alpine and Subalpine and the third, which appears in the Subalpine ecoregion, have similarly large negative Component 2 scores. Perhaps both of these latter points could be considered borderline Alpine.

The ecoregion groupings for each component (Table 5) proved to be significant at the 1% level of significance. This suggests that the first six components can be usefully applied to the climatic characterization of ecoregions.

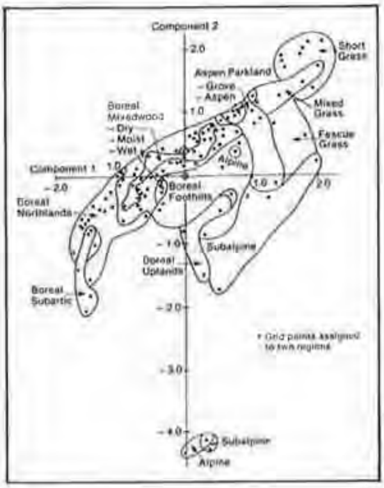

FIGURE 6 Component scores related to ecoregions

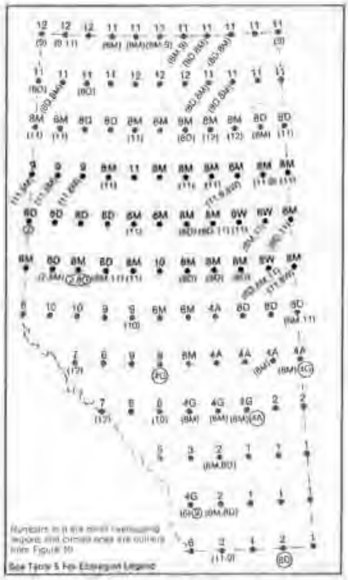

FIGURE 7 Ecoregion or subregion designation for each point

In determining the climatic index of agricultural potential (CA), a moisture factor is computed for each month using the estimated normal PE and precipitation with water budgeting procedures (Turc and Lecerf, 1972). For these procedures, it was necessary to assume some soil moisture holding capacity. In ecological land classification, as in agricultural land evaluation, a reasonable approach would be to perform the calculations using values to represent various soil textures. In agriculture in Canada, computations are often made for capacities of 100, 150, 200 and 280 mm, and similar capacities have been suggested for France by Turc and Lecerf (1972). They also state that lower capacities should be employed in calculations involving monthly normals, as opposed to monthly data for individual years. For use with normals they recommend 70, 120, and 170 mm instead of 100, 150 and 200 mm respectively. Following the example of the initial mapping for France, the calculations for Alberta in the present study were made using 70 mm as the soil moisture capacity, which is equivalent to 100 mm in calculations that are not based on normals. In further work for ecological land classification, the computations could be done for several capacities. The capacities to be considered depend on the soils, vegetation, climate and the length of the period of analysis, i.e. whether the calculations are for weeks, months or some other duration (Turc and Lecerf, 1972).

A heliothermic factor is also computed for each month. This is based on a solar factor derived from photoperiod or global radiation, whichever gives the smallest result, and a heat factor. The latter is calculated from mean temperature, but with modification by minimum temperatures for values close to freezing, and it is made equal to zero for sub-freezing minimum temperatures.

For each month the heliothermic is multiplied by the moisture factor. The 12 monthly indices so obtained are summed to derive the annual value of CA, the climatic index of agricultural potential. A computer program was prepared and applied to compute the index and related values for each of the 110 points. If a negative or zero value is indicated for either the moisture factor or minimum temperature for any month, the index value for that month is zero.

CA, as calculated here for Alberta, is generally highest around 53 to 56 degrees N latitude, particularly in the upper Peace River region (west of Lesser Slave Lake), with lower values to the north due to cold and in the southeast due to dryness (Figure 8). Zero values are encountered in the mountains. The single extreme highest value was at point 106, on the 49th parallel of latitude. It should be kept in mind that the values reflect the balancing effects of moisture, temperature and light. For a particular level of moisture and temperature, the index would increase northward due to the longer photoperiod. For a given combination of moisture, latitude, and altitude, it would increase westward, as temperature tends to increase westward on the Canadian Great Plains (Hopkins, 1968).

TABLE 4 Component score characteristics for each ecoregion

			COMPONENT 1				COMPONENT 2			
Name	No	N	H	L	M	V	H	L	M	V
Short Grass	1	8	2.11	1.48	1.75	.05	2.02	1.30	1.78	.05
Mixed Grass	2	5	2.05	1.02	1.47	.16	1.66	1.39	1.32	.04
Fescue Grass	3	2	1.82	1.38	1.60	.05	.77	.59	.68	.01
Aspen Parkland	4									
Groveland	4G	5	1.41	1.02	1.15	.02	1.22	-.11	.76	.21
Aspen	4A	5	.86	.52	.70	.01	1.02	.87	.93	.00
Subalpine	6	6	2.01	.00	.84	.44	.21	-4.35	-1.80	3.48
Alpine	7	3	.76	.00	.37	.10	.38	-4.35	-2.69	4.72
Boreal Mixedwood	8									
Dry	8D	13	.45	-1.01	-.08	.26	.74	-.51	.35	.13
Moist	8M	30	.81	-1.04	-.24	.27	.87	-.70	.13	.16
Wet	8W	3	.00	-.38	-.25	.03	.33	-.24	.00	.06
Boreal Foothills	9	7	.83	-.43	.17	.26	.49	-.97	-.22	.19
Boreal Uplands	10	4	.71	-.08	.35	.09	-.28	-1.55	-.82	.22
Boreal Northlands	11	18	-.60	-1.74	-1.32	.08	.02	-1.21	-.56	.11
Boreal Subarctic	12	6	-1.40	-1.64	-1.51	.01	-.82	-2.13	-1.40	.24

	COMPONENT 3				COMPONENT 4				COMPONENT 5			
No	H	L	M	V	H	L	M	V	H	L	M	V
1	3.24	1.68	2.34	.23	-.22	-1.80	-1.25	.22	.33	.09	.21	.01
2	3.06	1.25	1.77	.47	-.29	-1.72	-.92	.30	.35	-.01	.09	.02
3	2.61	.98	1.80	.66	1.79	.26	1.03	.59	.87	.03	.45	.18
4G	1.80	.72	1.17	.14	1.67	-1.72	-.60	1.41	.99	-.13	.15	.18
4A	.90	.04	.55	.09	-1.43	-1.70	-1.55	.01	-.07	-.32	-.20	.01
6	3.62	.38	1.57	1.50	8.01	.59	3.86	4.93	9.62	.50	3.42	12.74
7	2.56	-1.56	.46	2.83	3.86	-2.47	1.58	8.23	8.93	-.56	5.14	16.82
8D	.52	-1.78	-.75	.74	.72	-1.53	-.51	.41	-.11	-.65	-.37	.03
8M	.39	-2.19	-.56	.44	.38	-1.43	-.40	.21	-.08	-.95	-.42	.04
8W	.25	-.04	.11	.01	-.05	-.92	-.42	.13	-.70	-.27	-.23	.00
9	.07	-2.13	-.91	.70	1.09	-.41	.49	.25	.18	-.79	-.39	.12
10	-.14	-1.27	-.56	.19	1.38	-.17	.85	.40	.71	-.31	.05	.15
11	.83	-1.99	-.47	.61	1.39	-.68	.42	.44	.03	-.79	-.43	.05
12	-.02	-1.98	-.98	.56	1.81	-.13	.66	.51	.05	-1.24	-.66	.22

	COMPONENT 6			
No	H	L	M	V
1	-1.89	-3.73	2.88	.42
2	-.59	-3.27	-1.73	1.02
3	-1.17	-3.66	-2.42	1.55
4G	.13	-1.60	-.34	.38
4A	.04	1.00	.48	.10
6	1.18	-3.23	-.07	2.26
7	1.05	-1.34	-.15	.95
8D	1.06	.11	.61	.11
8M	1.40	.18	.76	.11
8W	1.51	.69	1.12	.11
9	1.36	.36	.81	.13
10	1.74	1.07	1.36	.07
11	.96	-.65	-.27	.14
12	.22	-.46	-.09	.05

NOTE:
No=Ecoregion Number
N=Number of grid points
H=Highest score
L=Lowest score
M=Mean
V=Variance

Data on the CA index have a number of applications. For examples, on land of similar soil suitability one would expect crop yield or biomass production at 53 N, 114 W, where CA= 9.16, to be about twice that of 50 N, 111W, where CA is 4.58. Crop yields and biomass production are aspects of ecosystem productivity, and thus of direct concern to ELC. Of course soil differences also contribute to crop yield differences. Actual yields are highest in the Olds-Three Hills area of Alberta, not in the Peace River area (K. Leggat, private communication, 1981). Points 90 and 91, which are just north of Olds and Three Hills, have CA values of 8.73 and 7.76, but the fact that the soils there are Chernozemiz, whereas in the Peace River area they are mainly the less productive Solonetzic and Luvisolic Great Groups, may help explain why the actual crop yields in the Peace River area are not as high as those of the Olds-Three Hills area.

Another application of CA would be in estimating the regional sensitivity of a sector such as agriculture to climatic change. For instance, one could subtract 1°C from certain monthly temperatures in the data for the region, re-compute CA, compute averages of CA weighted by farm acreage, and express regional impact as a percentage change in potential productivity by dividing the new weighted average CA by the old one.

There must be more to ecological land classification than total production or even biomass productivity, however. Points 50 N, 112 W, and 59 N, 117 W, have almost identical CA values, 4.56 and 4.55, but it would seem quite unreasonable to suggest that they should be considered as in the same ecoregion. One is low mainly because of cool temperature, the other because of dryness, and the resulting vegetation and land use potential would be quite different.

The results of the Turc index computations were then studied in relation to the ecoregions. Values of CA generally increase through regions 1, 2, 3, 4G to 4A (Figure 9, Table 6), are highest for 8D, 8M and 9, and decrease through 11 and 12, again reflecting relatively low values at one end due to dryness and at the other due to cold. The other four regions exhibit inconsistencies and it may be worth noting that not only are the sample sizes quite small in three of them, but also the spatial climatic models used in generating the climatic data work best at lower altitudes and could not be expected to give very satisfactory results, for example, for alpine and subalpine regions (7 and 6).

Since the heliothermic and moisture factors had been computed for each point, it was decided to see if it would be more helpful for distinguishing ecoregions to consider these separately. To summarize the monthly data to obtain annual values for these factors, it seemed reasonable simply to sum the 12 monthly values in each case, just as Turc had done with the CA index. The monthly heliothermic data were summed to obtain an annual value (HT), and an annual value (Fs) was computed by summing the monthly moisture values.

The use of Fs and HT separately showed considerably more encouraging results with respect to delineating regions. The Fs range of 2.14 to 2.73 uniquely distinguished the short grass region, 1, from all other regions, as none

TABLE 5 Analyses of variance of component scores for first six components*

COMPONENT	SOURCE OF VARIATION	F RATIO	SUM OF SQUARES	VARIANCE ESTIMATE
1	Between Ecoregions		101.53	7.81
	Within Ecoregions		19.54	.19
		41.11		
2	Between Ecoregions		105.85	8.14
	Within Ecoregions		49.02	.49
		16.61		
3	Between Ecoregions		122.90	9.45
	Within Ecoregions		66.84	.66
		14.32		
4	Between Ecoregions		148.36	11.41
	Within Ecoregions		92.17	.91
		12.54		
5	Between Ecoregions		164.17	12.63
	Within Ecoregions		133.67	1.32
		9.57		
6	Between Ecoregions		134.91	10.38
	Within Ecoregions		39.66	.39
		26.62		

* Note: The degrees of freedom for all components for between regions and within regions are 13 and 101 respectively.

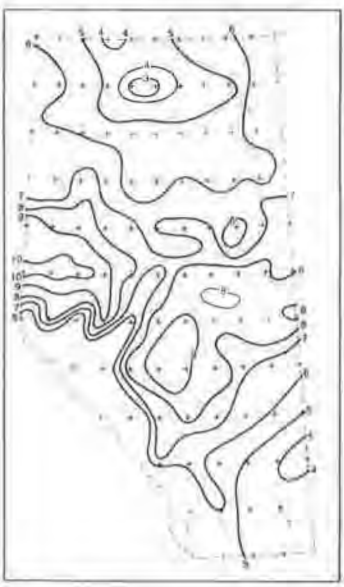

FIGURE 8 The climatic index of agricultural potential (after Turc)

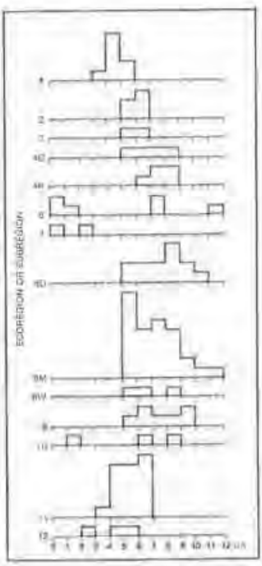

FIGURE 9 Histograms of CA by region

of the others had Fs below 2.8 (Table 6). There were no overlaps in Fs values among the grass regions 1, 2 and 3, but there were among these with CA. Similarly HT clearly distinguished between subregion 8D, boreal dry mixedwood (HT 19.69 to 26.45) and the boreal subarctic ecoregion (4.64 to 16.51) whereas there is some overlap between the CA values for these.

Examination of the results leaves very little doubt that there is a relationship between the mapped ecoregions on the one hand, and the computed values on the other, for all three variables, CA, Fs and HT. Variance analysis (Table 6) suggests that the differences from region to region were significant (P=.01). We would remark here that some of the assumptions usual in analysis of variance may not hold in this case, particularly that of homogeneity of variance among the samples, but we feel that this would weaken the argument only slightly. In further analysis of variance work with these data, appropriate tests of the assumptions need to be made, such as Bartlett's test for homogeneity of variance, and it might be desirable to keep the Cordilleran and uplands regions separate (6, 7 and 10) from the other regions in the analysis. The present results suggest that the most marked differences between regions are for Fs and HT, and these are the most relevant for delineating the regions.

To examine the relationship among Fs, HT and ecoregions more closely, HT was plotted against Fs on a graph and polygons were drawn, somewhat subjectively, joining the outer points in the group for each ecoregion, and the details of the overlap conditions were noted (Figure 10). Ecoregions 3 and 7 are represented by straight lines rather than polygons as there were only two points in each of these cases.

As expected, the points for ecoregion 1, at the warm, dry end of the plot, showed no overlap with any other. Region 6, at the wet, cool end, was also relatively free of overlap. For every other region there was at least some degree of overlap or ambiguity. Within most polygons, however, there were several points not involved in any overlap.

With the aid of the Fs-HT plot (Figure 10), each data point was assessed as to whether or not it fell in an overlap area, and if so with what other ecoregions (Figure 7). In some cases a single point, though not in an overlap area, was an outlier beyond an overlapping area. For example, point 50 N 114 W is in ecoregion 4G but on the plot it is an outlier beyond part of the 9 polygon. The occurrence of such outliers may be a function of the small number of sample points used here, or it may suggest the need for some revision of ecoregion boundaries.

The graphing of Fs against HT, and Component 1 against Component 2, resulted in the inadvertent illustration of one of the problems associated with spatial resolution and representativeness. Grid point 78 lies in a valley which is surrounded by much higher mountainous terrain. The region surrounding the point is ecologically classified as 'alpine'. Because the point was assigned both a lower elevation and an 'alpine' designation, the graphing of Components 1 and 2 (Figure 6) resulted in this point appearing as an alpine

TABLE 6 Statistics of annual values of Turc's variables, analysed by ecoregion

*	**	RANGE						MEAN			VARIANCE		
		HT		Fs		CA							
No	N	Low	High	Low	High	Low	High	HT	Fs	CA	HT	Fs	CA
1	8	22.72	28.89	2.14	2.73	3.84	5.95	27.22	2.45	4.71	3.23	0.05	0.35
2	5	23.36	25.31	2.90	3.73	5.39	6.60	24.22	3.38	5.96	0.47	0.07	0.16
3	2	19.40	21.28	4.01	4.29	5.41	6.93	20.34	4.15	6.17	0.88	0.02	0.58
4G	4	13.90	22.65	3.82	4.93	5.24	8.73	20.08	4.37	7.06	12.88	0.15	1.72
4A	5	22.33	23.79	3.90	4.21	6.33	8.79	23.09	4.05	7.64	0.35	0.01	0.80
5	0												
6	6	0.00	19.55	4.78	6.00	0.00	11.24	7.91	5.52	4.53	57.51	0.16	18.85
7	2	0.00	20.08	2.82	5.64	0.00	2.42	10.04	4.23	1.21	100.80	1.99	1.46
8D	13	19.69	26.45	2.81	4.02	5.87	10.32	22.47	3.35	7.96	3.25	0.10	2.00
8M	29	15.79	25.29	3.22	4.56	6.32	11.00	20.19	3.67	7.20	5.01	0.14	2.43
8W	3	17.11	20.53	3.75	3.93	5.55	8.38	18.81	3.82	6.97	1.95	0.01	1.33
9	7	8.67	20.59	3.51	4.83	4.89	9.89	16.83	4.23	7.53	14.78	0.22	2.58
10	3	2.08	13.63	4.50	5.40	1.34	8.34	8.77	4.91	5.25	23.91	0.14	8.51
11	17	13.92	21.82	3.14	4.19	3.92	6.77	19.98	3.67	5.41	3.33	0.07	0.72
12	6	4.64	16.51	4.04	4.35	2.00	5.96	11.31	4.17	4.13	24.73	0.02	2.53

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	HT Sum sqs.	HT Mean sq.	Fs Sum sqs.	Fs Mean sq.	CA Sum sqs.	CA Mean sq.
Among regions	13	2569.7	197.7	44.73	3.44	219.0	16.85
Within regions	96	1203.3	12.5	14.86	0.15	303.2	3.16
Total	109	3773.0		59.59		522.2	
F ratio		15.77		22.23		5.33	

* No Ecoregion/subregion

** N Number of grid points in each ecoregion/subregion

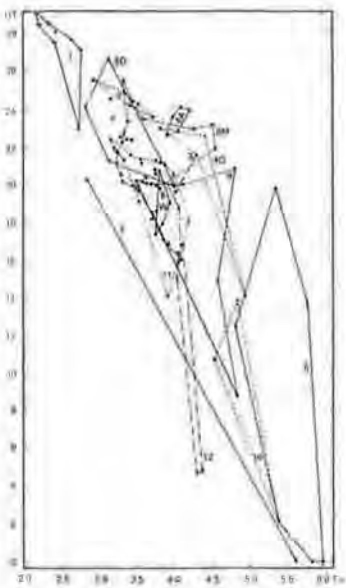

FIGURE 10 Fs and HT values related to ecoregions

FIGURE 11 Ambiguous (shaded) and unique (unshaded) classification areas using Fs and HT

location in the midst of boreal foothills. In the graphing of Fs against HT (Figure 10) point 78 was plotted as being drier than the dry mixedwood and almost as warm, and very different from the only other alpine (Region 7) point. In further discussion here, this anomalous point will be ignored, but in future work attention must be given to this type of problem.

Given Fs and HT values of any point, that location could tentatively be identified as belonging to one or more ecoregions. If the data place the point in a non-overlap area within a polygon (Figure 7), this tentative identification is unambiguous. Points occurring in overlapping areas may suggest possible bio-climatically intermediate transition zones. Points falling outside the boundaries of any polygon may do so for any of the number of reasons, including inadequate sample size and local anomalies.

In a few cases the overlap was only between subregions 8M, 8D and 8W. Disregarding such subregion overlaps, a diagram was drawn showing the areas with points which could be classified uniquely as to ecoregion, and the areas which would be ambiguously classified (Figure 11).

In mathematical terms, an overlap area reflects an intersection of sets, in this case an intersection between the set of combinations of Fs and HT for one ecoregion and that for another. In ecological terms, one interpretation of the areas on the map which have Fs and HT conditions that could indicate two or more ecoregions is that these areas are transition zones between different ecoregions. Possible interpretations of the overlap situation reflected in Figure 10 include:

1 The climatic specification (Fs and HT annual sums) may be inadequate. A more detailed breakdown may be needed, e.g. month by month data, or other variables, or an indication of year-to-year variation.
2 There may have been some data inadequacies in the drawing of the ecoregion map.
3 There may be problems relating to scale and spatial resolution. For example conditions at one of our data points may be atypical of the ecoregion in which that point appears, but this may be so local in nature that it would not have been appropriate to show it on an ecoregion map.
4 There may be a real intermediate zone in an ambiguous area. For instance, one could hypothesize such a zone between dry mixedwood and boreal northlands composed of varying proportions of areas typical of these two ecoregions, with the dry mixedwood occurring most often on south-facing slopes and boreal northlands on north-facing slopes.

All of the above interpretations may be valid to different degrees in various parts of the province.

Results of this study indicate that:

1. spatial climatic models and the application of a grid can be used to generate climatic data of particular relevance to ecological land classification, particularly at the ecoregion scale,
2. principal component analysis and Turc's climatic index of agricultural potential are two very different techniques, each with its own strengths and characteristics for transforming climatic data into two or three readily mapped bioclimatic indices suitable for inclusion in the process of ecological land classification, and
3. these methods may also be used to test, using analysis of variance techniques, the bioclimatic distinctiveness of ecoregions that have been drawn primarily on the basis of vegetation and soils information.

Such information has been provided here for most of Alberta, but the results are probably not satisfactory in the Cordilleran region of the province, as our spatial climatic models are not adequate for that area.

Because potential evapotranspiration was derived for the Turc index calculations using an equation of Baier and Robertson (1965), the actual Turc index values for Alberta will not be directly comparable with those published for areas such as France which used Turc's potential evapotranspiration formula (Turc and Lecerf, 1972). The values are internally consistent within the present study, however, and it is valid to use them for comparing the climatic resources of different parts of Alberta.

Principal component analysis gives greatest weight to those variables that are most interrelated with other variables in the set considered. A variable that is poorly related to other climatic variables will be given little weight, even though it may be quite important in the delineation and specification of ecoregions.

In future work, several of the variables used here could be omitted at the outset. Also, during the PCA the correlation matrix could be checked and cases of autocorrelation removed before proceeding.

The procedures for generating the climatic data in the Canadian Great Plains make it possible to use much greater spatial resolution than was used here, as an aid in objective map drawing. It would not be appropriate to do this in the Cordilleran region, however, because the spatial climatic models are not adequate there. In future work perhaps component loadings derived from PCA for the 110 points could be applied to climatic data for a much larger number of points to obtain component scores for mapping purposes.

In PCA, the fact that Component 1 (Figure 4) has relatively simple geographical patterns conforming largely to latitude, while Component 2 (Figure 5) shows patterns that tend to follow the contours of the land, is no doubt related to the fact that Component 1 is mainly winter temperature while 2 is mainly a summer temperature factor. On the Canadian Great Plains altitude tends to have the more important effect on temperatures in summer, while latitude generally has the greater effect in winter (Hopkins, 1968).

Our use of climatic data generated for grid points by spatial climatic models, rather than actual climatological station data, does not seem to have caused any particular problems in the principal component analysis.

From comparison of Figures 6 and 10 it appears that the PCA gives results that better distinguish among Alberta ecoclimates than do the Turc index data. The advantage of PCA might have been even greater had all the components, not just the first two, been incorporated into Figure 6. The PCA process identified temperature, primarily winter temperature and secondly summer temperature, as being of much greater significance than precipitation. The Turc index computations, on the other hand, give much more balanced attention to moisture and temperature. Further, because the monthly Turc index values are all set to zero where temperatures are below certain threshold conditions, regardless of how far below the thresholds they are, they tend not to reflect winter severity, which would be important in ecological land classification. Ultimately it will be desirable to identify the most relevant weighting of the importance of temperature and precipitation to ecological land classification and then to modify the techniques presented here.

Principal component analysis involves subjectivity when the general set of variables to be considered and data to be used are being determined, but is quite objective in specifying the precise formulation of the calculations. There is much to be said for using 'good judgement' in developing the form of the model for one's application. However, the climatic implications of ecoregion analysis are extremely complex, and we have no particular 'dependent variable' in mind. Use of subjective judgement may result in the personal bias of the analysts causing important variables to be overlooked. It is clear that both objective methods and considerable subjective judgement are required.

ACKNOWLEDGEMENTS

The 10-km grid square estimated precipitation normals for the prairies were provided to Agriculture Canada under contract by the Shawinigan Engineering Co., Montreal, Que. The authors also wish to gratefully acknowledge the helpful comments by members of several disciplines who reviewed preliminary drafts of the present paper.

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Des Erreurs Systematiques dans les Donnees Canadiennes de la Duree d'Ensoleillement?

André Hufty et *Marius Thériault*

SUMMARY: Fundamental errors in Canadian sunshine data?

Data on amounts of daily sunshine published by the Canadian Meteorological Service should be employed with great care because of two fundamental errors in them which are not immediately obvious to the user. First, an error known as the "horizon effect" occurs at stations located in valleys or those surrounded by tall buildings or trees. The actual amount of sunshine may be blocked by objects such as these "on the horizon". To correct this ambiguity, the Meteorological Service should, at the very least, publish local correctional coefficients for all Canadian stations. The second error is equipment induced. It results from the inability of the Casella-London sunshine recorder to measure accurately the amount of sunshine during the equinoxes because the paper used by the Meteorological Service is too long. It would be interesting to evaluate the effects of this error, especially upon the precision of solar radiation models calibrated using these data.

Dans le cadre d'une recherche portant sur la distribution régionale et saisonnière du rayonnement solaire au Québec, entreprise depuis cinq ans au Laboratoire de climatologie de l'Université Laval (voir Lecarpentier, 1973; Periard, 1982; et Boutin, 1980)[1], nous avons fait une étude systématique des durées d'ensoleillement. Pour réaliser ce travail, nous avons utilisé les données dépouillées à partir des enregistrements des héliographes de type Campbell-Stokes, publiées depuis 1916 par le Service météorologique du Canada dans le périodique *Résumé mensuel, Données météorologiques pour le Canada,* et consignées dans un fichier informatique constitué par le Service de la météorologie. Elles ont par la suite été réduites en "normales" qui font l'objet de publications officielles (S.M.C., 1968; Yorke et Kendall, 1972) et la Direction de la météorologie du Ministère canadien des transports a publié, en 1968, des cartes mensuelles et annuelles du nombre d'heures d'insolation au Canada durant la période 1931-1960. Pour notre recherche, nous avons résolu de construire des cartes plus détaillées pour le Québec en utilisant la même source d'information.

Les valeurs mensuelles moyennes de la période 1941-1970, publiées en 1972 par Yorke et Kendall, ont été pointées sur des cartes du réseau québécois qui compte environ 80 stations actives situées en majorité dans la vallée du Saint-Laurent. Toutes les tentatives d'interpolation sur ces cartes ont conduit à

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des impasses en raison de différences très marquées entre des stations distantes de quelques dizaines de kilomètres. Par exemple, dans la région métropolitaine de Québec, les auteurs publient les valeurs annuelles pour cinq stations situées dans un quadrilatère d'environ 50 kilomètres de côté: Québec A: 1738 heures; Vallée Jonction: 1607 heures; Duchesnay: 1819 heures; Saint-Augustin: 2036 heures; et Québec (Les plaines): 1708 heures. Notons qu'il s'agit de moyennes à long terme et que les écarts relatifs notés dépassent les 20% du total annuel de la zone. Pour l'ensemble du Québec, l'écart et d'environ 600 heures entre le nord et le sud de la province selon Yorke et Kendall. Dans ces conditions, il est évident que l'erreur d'interpolation mathématique dépasse largement l'intervalle représenté par les isolignes qui figurent sur la carte. Des essais ont alors été entrepris pour relier les différences notées à des variations des conditions géographiques régionales. Ils furent tous infructueux.

Une étude exhaustive des écarts s'imposait. La première étape de vérification des données implique une comparaison des durées journalières maximales d'ensoleillement observées sur une longue période avec les durées astronomiques d'éclairement (durées du jour). Le procédé graphique suivant a été utilisé (voir figures 1 et 2): on a d'abord tracé les durées théoriques du jour pour des hauteurs angulaires du soleil de 0 à 5 degrés au-dessus de l'horizon, pour tenir compte de la sensibilité du système "boule de verre-type de papier"; on a ensuite reporté sur ce graphique, pour chaque stations du Québec, les durées maximales journalières de l'insolation observée pendant 10 ans, ce qui a permis de dégager les trois situations suivantes:

1 les maxima journaliers observés coïncident avec les courbes théoriques, entre 1 et 4 degrés;
2 l'ajustement est satisfaisant mais on note des décrochements saisonniers au printemps et à l'automne;
3 les maxima observés sont inférieurs aux courbes théoriques toute l'année.

L'analyse des stations qui appartiennent aux trois catégories nous a donné les résultats suivants:

1 seules 14 stations, soit moins de 20% du réseau, présentent des courbes sans corrections appréciables, si l'on admet une imprécision de quelques degrés pour un soleil bas sur l'horizon; elles sont équipées d'héliographes de marque Lambrecht et ont un tour d'horizon dégagé de tout obstacle;
2 14 stations appartiennent au groupe 2, c'est-à-dire avec un décrochement significatif des courbes équinoxiales et elles sont équipées d'héliographes de marque Casella-London.

En étudiant d'autres stations canadiennes, nous avons rencontré le même problème, notamment à Goose Bay (Labrador) et à Toronto Meteorological Research (Ontario), station pour laquelle nous avons produit le même type de graphique, mais en utilisant toutes les données journalières de 1972 à 1976 (figure 1). Après maintes hypothèses, nous avons finalement identifié la

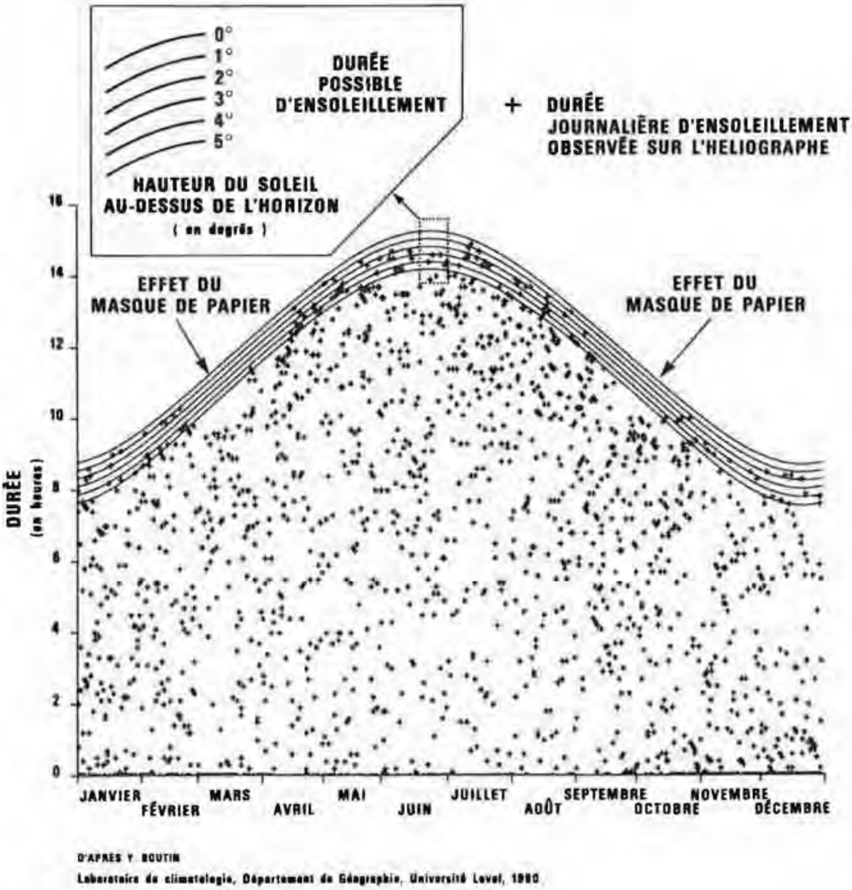

FIGURE 1 Toronto (Meteorological Research Station) Durée journalière d'insolation mesurée sur l'héliographe, 1972-1976

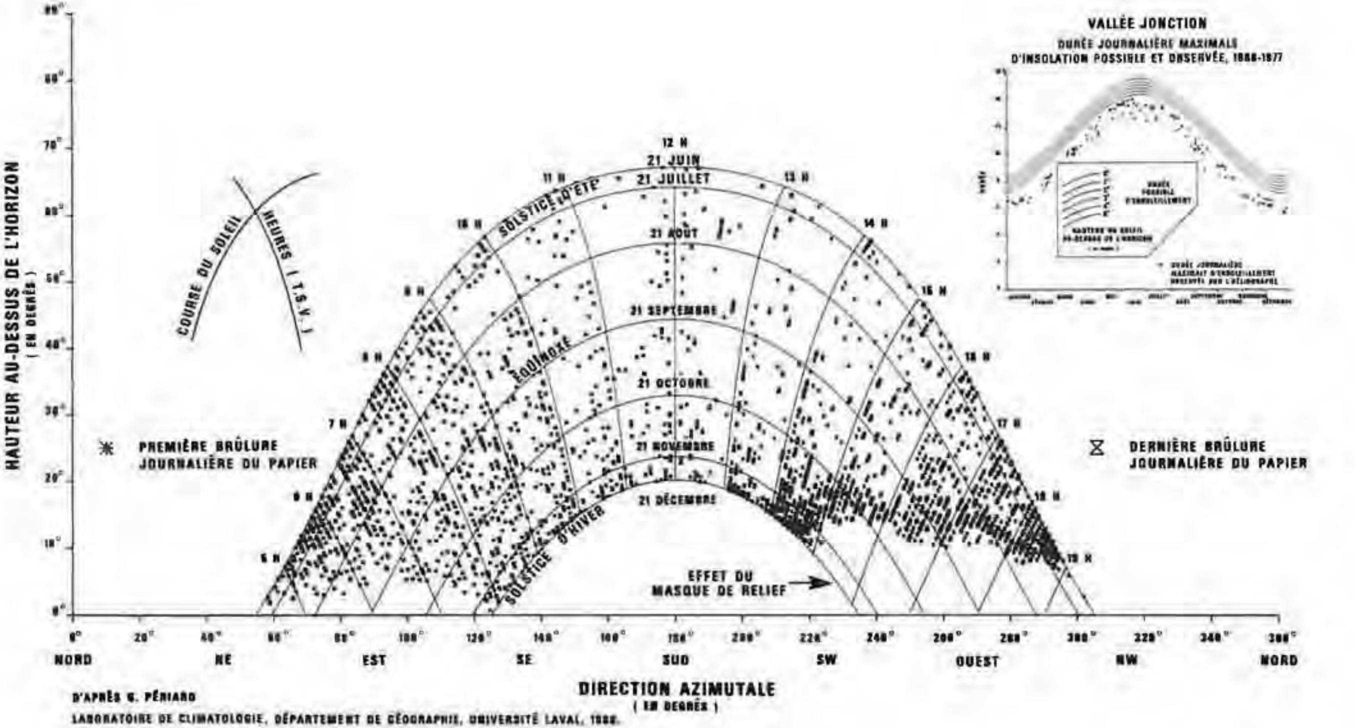

FIGURE 2 Positions du soleil au moment de la première et de la dernière brûlure journalière du papier sur l'héliographe seule la limite determinée par les hauteurs les plus basses du matin et du soir est significative Vallée Jonction, 1968-1977 (latitude 48° 23')

cause du mal: il s'agit d'une erreur instrumentale de type primaire que des règles élémentaires de contrôle auraient pu détecter à tout le moins pour la station principale d'un réseau national. On sait que ces héliographes sont munis de trois tables d'enregistrement qui permettent d'ajuster la lecture à l'angle d'inclinaison de la course du soleil au-dessus du plan local. La table du centre est utilisée aux équinoxes (printemps et automne); à cette saison, le soleil se lève près de l'est et se couche près de l'ouest; ou, l'emploi systématique d'un papier d'enregistrement trop long masque le soleil tôt le matin et tard le soir, ce qui empêche l'appareil d'enregistrer l'insolation (voir figure 3). La perte d'enregistrement atteint jusqu'à deux heures par jour aux équinoxes (22 mars et 22 septembre) et varie selon la latitude. Ce problème est important sur environ vingt pourcent du réseau québécois, ce qui crée une descente anormale et "locale" de certaines moyennes printannières et automnales d'ensoleillement. Si les stations étaient toutes installées suivant les normes internationales (horizon dégagé), ce problème affecterait près de la moitié du réseau.

3 Le reste du réseau, soit 54 stations, est affecté de deux types d'erreurs et les décrochements systématiques de la troisième catégorie sont plus délicats à traiter car il s'agit de repérer tous les obstacles qui gênent la brûlure du papier. Nous avons dépouillé les valeurs horaires d'ensoleillement sur le fichier informatique pour déterminer l'heure d'apparition du soleil sur l'appareil le matin et l'heure du dernier enregistrement le soir; ces heures ont été ensuite surimposées sur des diagrammes des coordonnées azimutales et d'élévation des courses saisonnières du soleil sur la sphère locale (figures 2 et 3). Deux "masques" différents apparaissent: le masque instrumental de papier (figure 3) qui laisse une trace symétrique et la masque dû aux obstacles permanents (troisième catégorie, figure 2) qui n'affecte que certaines directions azimutales et dont l'effet varie d'une saison à l'autre.

C'est d'ailleurs avec stupéfaction que nous avons constaté que les données d'ensoleillement publiées et utilisées à date au Canada ne semblent pas avoir été corrigées de l'effet du relief local dont les répercussions sont très variables d'un site à l'autre et d'une saison à l'autre (déplacements saisonniers des directions du lever et du coucher du soleil); une comparaison des diagrammes avec des tours d'horizon évalués au théodolite en collaboration avec le Service de la météorologie du Québec a confirmé nos déductions bien qu'il faille se méfier de la défoliation des arbres en hiver, des déménagements des stations et de l'ajout de nouvelles constructions autour du site de mesure.

Sur cette base, nous avançons l'hypothèse que les travaux réalisés à ce jour sur les durées d'ensoleillement au Canada sont à utiliser avec précaution. On saisit les implications d'une telle remarque quand on réalise que ces données sont utilisées pour identifier des potentiels agricoles (photo-période), architecturaux (énergie solaire) et dans les modèles d'évaluation du bilan énergétique qui font intervenir la formule d'Angström. Il y a certainement une sous-estimation

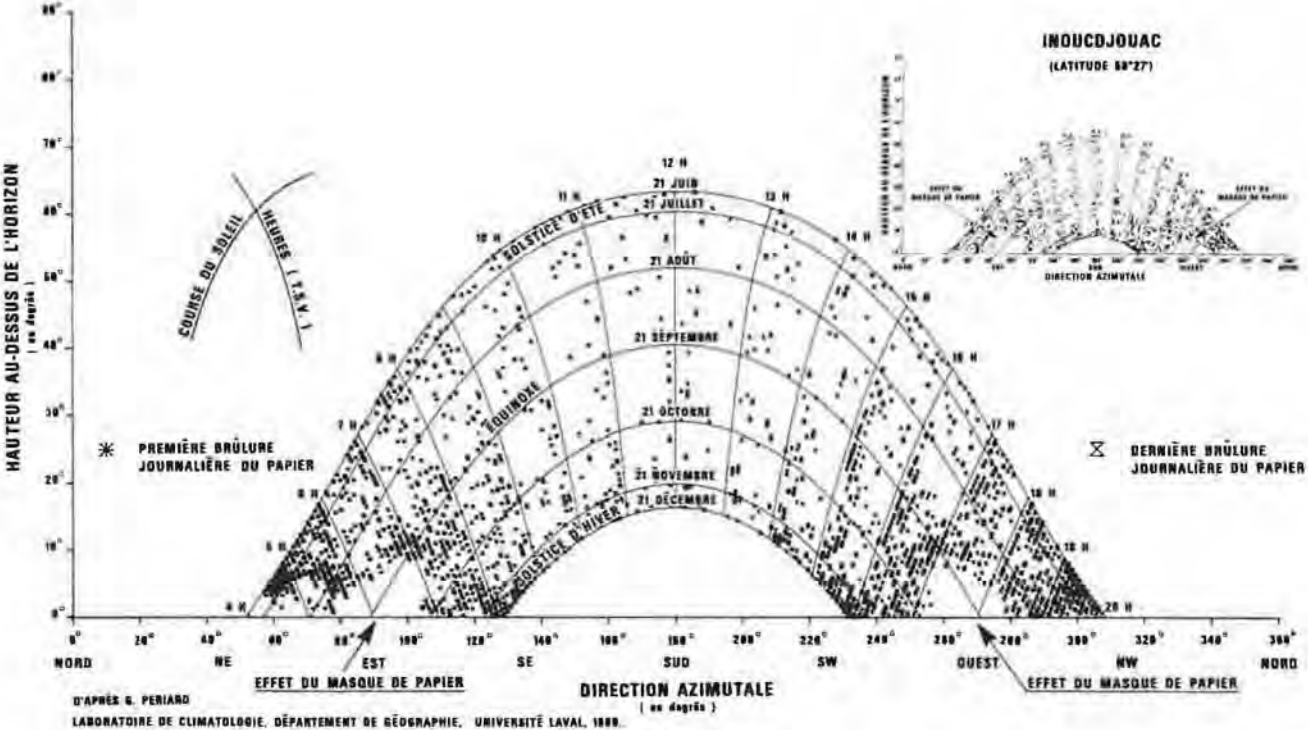

FIGURE 3 Positions du soleil au moment de la première et de la dernière brûlure journalière du papier sur l'héliographe seul la limite determinée par les hauteurs les plus basses du matin et du soir est significative Natashquan, 1968-1977 (latitude 50° 12')

de la réalité pour les très belles journées, autour des équinoxes; pour les journées où dominent des nuages cumuliformes, il peut y avoir une compensation entre les erreurs[2]: d'une part, l'héliographe surestime les heures de soleil à cause d'une brûlure trop grande du papier quand les conditions du ciel varient rapidement et, d'autre part, il y a surestimation des heures théoriquement possibles. Cependant, compter sur une compensation d'erreurs pour obtenir parfois une mesure correcte ne remplacera jamais une étude sérieuse des corrections.

En conclusion, nous adressons les demandes suivantes à Environnement Canada:

- de fournir les coefficients locaux de correction propres à rétablir les moyennes mensuelles et journalières correctes, en publiant non seulement les tours d'horizon mais également des facteurs mensuels de correction, calculés à partir des données journalières pour les très belles journées;
- de ne pas oublier, en faisant ce travail, de s'assurer que ces corrections sont stables sur de longues périodes (déménagement de stations, modifications du site ...);
- de prévenir l'usager, dans les notices des publications de données de rayonnement solaire, de l'absence ou non de corrections, notamment dans les cas suivants: correction de masque de relief et de masque d'anneau équatorial (rayonnement diffus).

NOTES

1 Pendant toute cette période, le Laboratoire de climatologie de l'Université Laval a collaboré avec le Service de météorologie de Québec qui poursuivait certaines recherches analogues. Au cours du printemps 1980, nous leur avons signalé l'absence gênante des "tours d'horizon", lacune qui fut comblée rapidement par leurs soins pendant l'été. Au même moment, nous avons trouvé et résolu l'erreur systématique commise aux équinoxes sur la moitié des stations du réseau à cause d'un mauvais emploi du papier; nous en avons de suite informé le Service de météorologie qui n'avait jamais repéré cette erreur auparavant. R. Leduc et C. Calvet ont publié cette question dans la revue *Atmosphère-Océan* en 1981 en omettant de citer le Laboratoire de climatologie en référence, lacune comblée en 1982 (voir bibliographie).

2 Cette remarque nous a été suggérée par un des correcteurs de l'article.

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News and Comments

RETIREMENT OF B.J. GARNIER, McGILL UNIVERSITY

At McGill University's Fall Convocation ceremonies, held on November 24, 1982 at Place des Arts in Montreal, retiring Professor B.J. Garnier was honoured with the title Professor Emeritus. J. Brian Bird of the Department of Geography provided a testimonial, citing Garnier's well-known work on the climate of New Zealand, as well as his efforts at editing and producing the Climatological Bulletin since its inception in 1967.

A reception was held in his honour that week. The menu design was similar to the cover of the pre-1983 Bulletin, complete with the McGill crest. Items on the menu were as follows:

——— Isobar ———

Menu Climatologique

Apéritif – assiette parisienne à la lapse rate

Veal Cordon Bleu à la manière du roi Garnier

Vegetables à la Thornthwaite

Potato gaspésienne

Rolls of thunder

Castelli Romani vin de rayonnement solaire

Koeppen BW-S Crème de menthe parfait

Water balance

Thé, Café

Post-dinner fare consisted of synoptic view, meteorological analysis, Coriolis deflections and long range views, albedos and other reflections, precipitations and responses, climatological reviews and projections, and turbulence and vorticity.

We wish Ben Garnier all the best on his retirement, and good weather wherever he travels.

GREAT LAKES INSTITUTE, UNIVERSITY OF WINDSOR

Marie Sanderson of the University of Windsor has submitted the following report on recent activities at the newly established Great Lakes Institute, where she serves as Director:

"Of interest to the readers of the Climatological Bulletin is the recent establishment of a Great Lakes Institute at the University of Windsor. It is unique in being the only university based Institute in Canada devoted to Great Lakes studies. Windsor's position in the centre of the Great Lakes Basin makes it an ideal location for such an Institute."

"The Institute is multi-disciplinary, with members from twelve departments at the University: engineering, chemistry, biology, geology, geography, political science, economics, law and education, as well as from the International Joint Commission and the Fisheries Research Station at Wheatley."

"The Director, Marie Sanderson, is a climatologist with the department of geography. The Executive Council of the Institute has members who are eminently qualified to give advice in environmental matters. Among these are James Bruce, A.D.M., Atmospheric Environment Service, Art Collin, Assoc. D.M., Energy, Mines & Resources, and Walter Giles, A.D.M., Ontario Ministry of the Environment."

"The major current research effort of the Institute is a case study of selected toxic contaminants in the Essex region. The contaminants chosen are two trace metals – lead and cadmium, and two organics – PCB's and octachlorostyrene. The research team of twenty scientists hope to look at these contaminants with an ecosystem approach – emissions, transport, surface loading, effects on flora and fauna, cost benefit analysis, legal implications and educational issues. The research is being funded over a three-year period by the Department of the Environment with an $800,000 contract with the Institute."

"The Institute plans to operate the Baie du Doré research and study centre on Lake Huron this year and bookings can be arranged by writing to the Institute office at the University of Windsor."

"A recent successful activity of the Great Lakes Institute was the hosting, in January, 1983, of the special winter meeting of the International Association for Great Lakes Research, marking twenty-five years of Great Lakes conferences."

COMMENTS ON "CLIMATOLOGY IN CANADA – A LOOK FORWARD"

In response to "Climatology in Canada – a Look Forward" by S.J. Cohen, which appeared in the October 1982 issue, Peter J. Lamb of the Illinois State Water Survey sent in several items on related issues.

One article, "Persistence of Subsaharan Drought" by P.J. Lamb, reprinted from Nature, Vol. 299, presents evidence that this well-known drought may not have ended in 1973. His updated rainfall index for the region indicates that rainfall was below average every year during the 1970-1981 period. Why then has there been so little publicity given to this continuing rainfall anomaly? Lamb speculates that the recent decline in population led to a reduction in the socio-economic impact of the drought. Rather than witnessing a shift in weather patterns, we are probably seeing the effects of a long-established strategy of adaptation to climate variations – emigration to more hospitable climatic regions.

Another item of interest is "On the Present and Potential Use of Climate Information by the U.S. Private Agricultural Sector" by P.J. Lamb, S.T. Sonka, and S.A. Changnon, Jr., which appears in Preprints of Sixteenth AMS Conference on Agriculture and Forest Meteorology. The authors contend that we have yet to develop the management strategies necessary to reduce the unfavourable consequences of climatic variation on agriculture. This leads to questions regarding the usefulness of climate impact assessment programs initiated by the U.S., as well as Canada. Climate data and information are used extensively by grain and brokerage companies, as well as seed and food canning industries in the U.S. However, the agribusiness community sees little dividend in the sophisticated use of climate data because of our inability 1) to provide accurate long-range forecasts at local scales, 2) to demonstrate applications of available data to management problems, and 3) to "package" data and information in formats appropriate to the users. To overcome these obstacles, the authors conclude that long range (up to 6 months) forecasts will have to be improved, and considerable user education will be necessary before an individual company or farmer will use climatic predictions on an ongoing basis.

Corrigendum

Author S.J. Cohen has noted the following errors in his article, "Climatology in Canada – A Look Forward" (Climatol. Bull., 32, 1-8):

1 On p. 3, lines 10 and 11 should read "... literature (e.g., Masterton et al., 1976; Mather, 1974; McQuigg, 1975, in Slater and Levin, 1981; Allsopp et al., 1981; Murphy, 1977; Murphy et al., 1977; Oliver, 1981; Rosenberg, 1974, in Slater and Levin, 1981; Thomas, 1981) much ..."

2 On p. 7, the following reference should be included:
Daniel, H., 1980. Man and Climatic Variability: The World Climate Programme. World Meteorological Organization, No. 543, Geneva.

The new symbol for Canadian Meteorological and Oceanographic Society which is shown on the cover was designed at University of Toronto Press by Beth Earl.

The Image

The symbol depicted is comprised of three elements of the natural world: air, water and ice. The initial impression is of ice, then ice in water, and then atmosphere surrounding both.

The 'arrowhead' iceberg points upward to suggest growth, positive research, and mobility, and the clean, clear, uncomplicated lines suggest the open, new directions of the Society. The floating shape suggests another aspect of the membership, that of balance and stability.

The emphasis on ice is appropriate for this Canadian society. Canada's research position in atmospheric and oceanographic studies indicate this as a potential area of specialization. This very Canadian aspect is appropriate in its uniqueness.

The square shape works well conceptually and graphically; it represents the unity of natural elements; it creates a clean, strong shape that is appropriate to many applications.

The name of the Society, in English and French, is used at the base of the symbol in a formal, modern style.

Le nouvel emblème de la Société Canadienne de Météorologie et d'Océanographie, qui figure sur la couverture, a été dessiné aux Presses de l'Université de Toronto par Beth Earl.

Le Dessin

Cet emblème se compose de trois éléments du monde naturel: l'air, l'eau et la glace. Ce qui retient d'abord l'attention c'est la glace, puis la glace dans l'eau et enfin l'atmosphère qui les entoure.

L'iceberg "en fer de lance" est dirigé vers le haut, donnant ainsi une idée de croissance, de recherche et de mobilité; les lignes parallèles simples, nettes et droites représente la nouvelle direction très souple prise par la Société. L'iceberg qui flotte se réfère à une autre caractéristique de l'association: équilibre et stabilité.

Que l'accent soit mis sur la glace convient particulièrement à cette société canadienne. En raison de la place occupée par le Canada dans le champ des études atmosphériques et océanographiques, il se peut que cela devienne un domaine de spécialisation. C'est là un des aspects uniques du Canada.

D'un point de vue conceptuel et graphique la forme carrée convient tout à fait: elle représente l'unité des éléments naturels et donne une impression de force et de netteté dont le symbolisme est plurivalent.

Dans un style à la fois moderne et conventionnel, le nom de la Société figure, en anglais et en français, au bas de l'emblème.