

DIURNAL AND SEASONAL STRUCTURE OF THE CLIMATE AT SCHEFFERVILLE, QUEBEC

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ABSTRACT

A method for the graphical analysis of diurnal and seasonal structure of climatic variables is presented; graphs of long-term means and standard deviations for each variable show the pattern and predictability of the climate. The 1953 through 1970 hourly weather records for Schefferville, Quebec (54°48'N, 66°49'W), are analyzed to illustrate the method. Graphs of estimated shortwave radi-

ation flux, air temperature, vapor pressure, wind speed, and probability of measurable rainfall characterize the site. The distinctive diurnal and seasonal structure of the climate is readily apparent in the graphs. The method may be useful in explaining plant and animal adaptations that are effected by the diurnal and seasonal patterns of climatic events.

INTRODUCTION

The relationships between climate and biological phenomena provide challenging problems for biologists and geographers. In studying these relationships, climatic structure is most often characterized by climate diagrams (Walter and Lieth, 1960), various synthetic indices (Thorntwaite, 1948), maps of climatic variables, or extensive tabular summaries drawn from weather service records. These methods prove satisfactory only when a more or less qualitative climatic basis for biological phenomena is sought. For example, the correspondence between vegetation and climate can be illustrated using climate diagrams (Walter, 1973), but a plant autecological study often requires analysis of diurnal

and seasonal climatic patterns. Similarly, the distributional limits of an animal may be related to mapped climatic variables but understanding its diurnal and seasonal behavior may require more detailed climatic analysis.

This paper gives a simple graphical method, derived from earlier work (Wang and Suomi, 1958; Wang, 1961; Troll, 1965), for studying the diurnal and seasonal structure of climate. An analysis of the 1953 through 1970 hourly weather records from Schefferville, Quebec (54°48'N, 66°49'W), is used as an example. The McGill Sub-Arctic Research Laboratory at Schefferville is a focal point for biological and climatic research in the Subarctic (Adams *et al.*, 1974). The climatic analysis presented here complements that of Tout (1964) which was based on daily weather records. Wilson (1971) and Barry (1959) discuss the Schefferville climate in the context of Quebec as a whole.

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METHODS AND MATERIALS

DATA SOURCES

Hourly surface observations (card type 1) administered by the Atmospheric Environment Service of Environment Canada offer a detailed climatic record for Schefferville. These records include various data of biological interest such as thunderstorm occurrences, rainfall classes, drizzle, snowfall classes, fog, atmospheric pressure, dry- and wet-bulb air temperatures, wind speed and direction, and cloud heights and types. These hourly data were analyzed for the 18-yr period 1953 through 1970. From January 1954 through March 1970 data were taken by the McGill Sub-Arctic Research Laboratory in Schefferville, Quebec at an elevation of 521.5 m. Anemometer height ranged from 10.1 to 14.6 m with a weighted mean height of 12.3 m. The minor site-related differences in the 1953 records (McCloughan, 1961) and in the 1970 records are inconsequential here. For some stations additional records can be obtained for hourly rainfall (card type 3) and hourly radiation fluxes (card type 11). Indexes are available to Canadian climatic data (Parker and Anderson, 1969; Parker, 1972) and climatic maps (Thomas and Anderson, 1967; Thomas and Parker, 1969).

ESTIMATION OF HOURLY SOLAR RADIATION

Like many stations, reliable records of hourly solar radiation flux are not available for Schefferville. The card type 1 records, however, contain data on cloud type and sky cover which may be used to estimate the solar radiation regime. Assuming clear sky conditions, global solar radiation was predicted using the computer program of McCullough and Porter (1971) with atmospheric properties characteristic of the Schefferville area. The attenuation of this clear sky estimate under cloudy conditions depends primarily on cloud type, cloud cover, and solar altitude (Kondratyev, 1969; Sivkov, 1971). The attenuated hourly global solar radiation, Q , was estimated using a formula of the Savinov-Ångstrom type (Gates, 1969: 55):

$$Q = Q_0 [1 - (1-k)]C \quad (1)$$

where Q_0 is the predicted clear sky global solar radiation, C is the total cloud cover in tenths, and k is the ratio of solar radiation beneath complete overcast to that under a clear sky. Table 1 gives the attenuation factors and the daytime frequencies of occurrence for

TABLE 1
Daytime cloud parameters affecting the estimation of global solar radiation^a

Type of lowest cloud	Attenuation Factor (k)	Annual daytime % frequency	Summer-autumn daytime % frequency
None	1.00	3.95	0.81
Fog	0.24	1.68	1.72
Stratus	0.23	17.17	21.97
Stratocumulus	0.32	22.29	24.64
Cumulus, Cumulonimbus	0.48	20.49	34.97
Altostratus	0.44	1.44	0.43
Alto cumulus	0.60	8.82	6.14
Cirrus	0.77	3.55	2.08
Cirrostratus	0.70	1.31	0.38
Nimbostratus	0.22	0.09	0.12
Cirrocumulus		0.20	0.12
Obscuring phenomena		19.01	6.62

^aThe attenuation factor k for each cloud type, estimated from data in Gates (1969) and in Pyldmaa and Timanovskaya (1972), represents the ratio of global solar radiation under a completely overcast sky of the cloud type to that under a clear sky. The estimates of daytime annual percent frequency for each cloud type during 1953-1970 are based on 79314 hours. The summer-autumn daytime percent frequency, based on the period 25 June through 1 November of 1953-1970, includes 29701 hours. The frequency of cloud types helps one to judge possible errors in the estimation of solar radiation flux.

cloud types at Schefferville. This represents a simplified, practical, but somewhat inaccurate approach to estimating solar radiation (Sivkov, 1971; Lechowicz, 1976).

GRAPHICAL ANALYSIS OF CLIMATE

We wish to examine both the diurnal and seasonal pattern of selected climatic variables and the variation from year to year about this mean climatic structure. The mean pattern is established from records for each hour of each day over 18 yr. The standard deviations of these data provide an indication of the diurnal and seasonal patterns of climatic variability. This analytic strategy is illustrated here using the Schefferville data on estimated global solar radiation flux, dry-bulb air temperature, wind speed, and vapor pressure. The means and standard deviations could not be calculated for rainfall, because the data were not recorded as a continuous variable on card type 1. Instead frequency of measurable rainfall was calculated for each hour of the year based on the 18-yr data record. All these calculations are easily made using standard statistical program packages available at university computing centers.

We used the cross-tabulation program, CROSTAB2, at the Madison Academic Computing Center to construct 365 day \times 24 hour matrices for each climatic variable. Transformation algorithms in the same statistical rou-

tine package may conveniently be used to adjust units of measurement, calculate synthetic variables such as radiation flux or vapor pressure, allow for leap year entries, and check for missing data. As this matrix is tabulated from the original data, CROSTAB2 stores sums of squares and number of entries in each matrix cell to calculate standard descriptive statistics. For each continuous variable, output from CROSTAB2 included the mean and standard deviation in each matrix cell based on the 18 yr data. For variables such as rainfall classes, CROSTAB2 calculated the frequency of rainfall in each cell of the 365 day \times 24 hour matrix. This frequency, calculated for each hour by dividing hours with any measurable rain by the total hours of data in that cell, is an estimate of probability of rainfall in each hour. The program SMOOTH was used to prepare these output matrices for the contour plotting program. The value in each matrix cell was adjusted by considering the weighted average of it and the 24 surrounding cells. If some of the weighting cells fall outside the matrix limits they are disregarded. Figures in Lechowicz (1976) show that the smoothing algorithm does not change the underlying climatic pattern. The matrices of smoothed values are used in the program CONTR to graph the diurnal and seasonal patterns of the selected climatic variables (Figures 1-5).

RESULTS

The climatic variables that affect energy exchange are of primary importance in biological studies. The general energy balance (Monteith, 1973) equation is:

$$R + M = C + \lambda E + J + G \quad (2)$$

where R is flux of net radiation, M is flux of metabolic heat, C is convective flux, λE is evaporative flux, J is rate of change of stored heat, and G is conductive flux. The shortwave radiation flux, estimated here but sometimes available from hourly weather data, provides the major input to the energy balance. The longwave radiation flux contributes to the net radiation flux but is only rarely measured; it may be estimated for clear sky conditions (Idso and Jackson, 1969) from air temperature. The energy dissipation terms are directly affected by air temperature, atmos-

pheric vapor pressure, and wind speed. Particularly for plants, rainfall has important indirect effects on energy exchange through the tissue water balance.

The seasonal and diurnal behavior of five climatic variables important in the energy balance equation were analyzed for the 1953-through-1970 period at Schefferville, Quebec: (1) estimated shortwave radiation flux, (2) dry-bulb air temperature, (3) wind speed at a mean height of 12.3 m, (4) vapor pressure, and (5) the probability of any rainfall greater than .25 mm during the hour.

The estimated shortwave radiation flux (Figure 1) shows a regular seasonal and diurnal pattern. Day length changes seasonally as expected (List, 1971). Maximum radiation fluxes occur between 1100 and 1400 h all year; during May and June these midday fluxes reach their annual mean maximum of

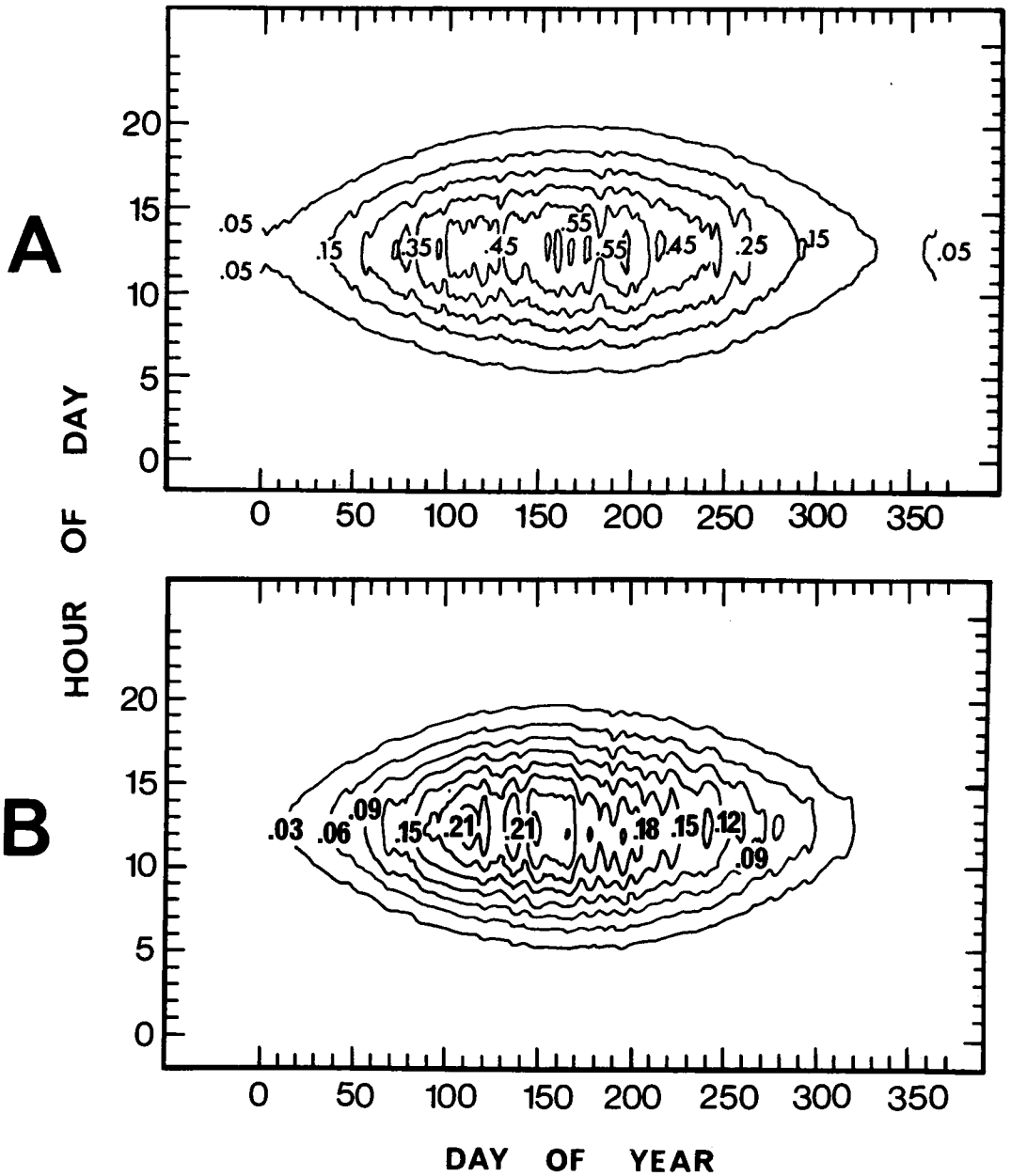


FIGURE 1. The annual and diurnal patterns of estimated shortwave radiation flux at Schefferville, Quebec, based on hourly weather records from 1953 through 1970. Isopleths are $0.1\text{-cal cm}^{-2}\text{ m}^{-1}$ intervals in Figure 1A which shows the mean fluxes and at $0.03\text{-cal cm}^{-2}\text{ m}^{-1}$ intervals in Figure 1B which shows the standard deviations about these mean fluxes.

$0.55\text{-cal}\cdot\text{cm}^{-2}\cdot\text{m}^{-1}$. Estimated radiation fluxes ranged up to $1.07\text{-cal}\cdot\text{cm}^{-2}\cdot\text{m}^{-1}$. Variability about this mean pattern is greatest in March, April, and May.

The annual air temperature regime (Figure 2) reflects the continental character (MacKay and Cook, 1963) of central Labrador-Ungava. Mean temperatures range

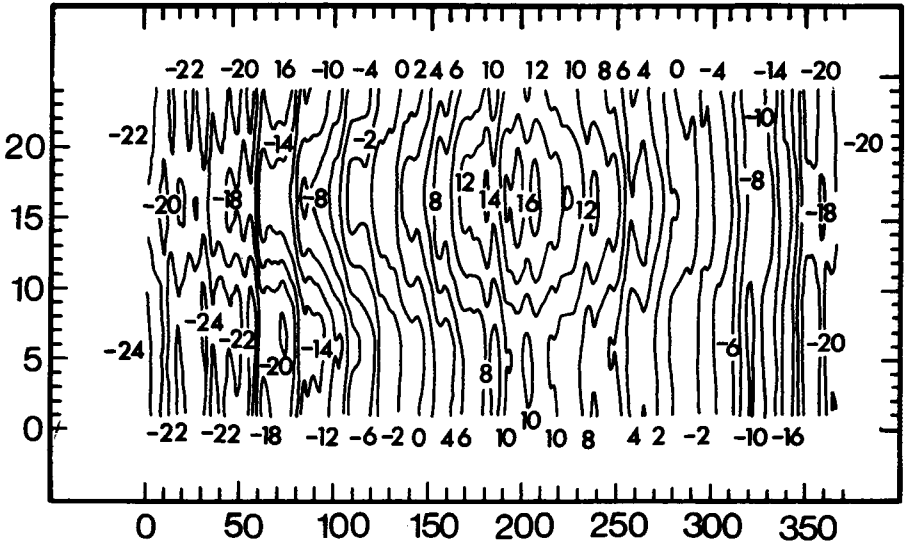
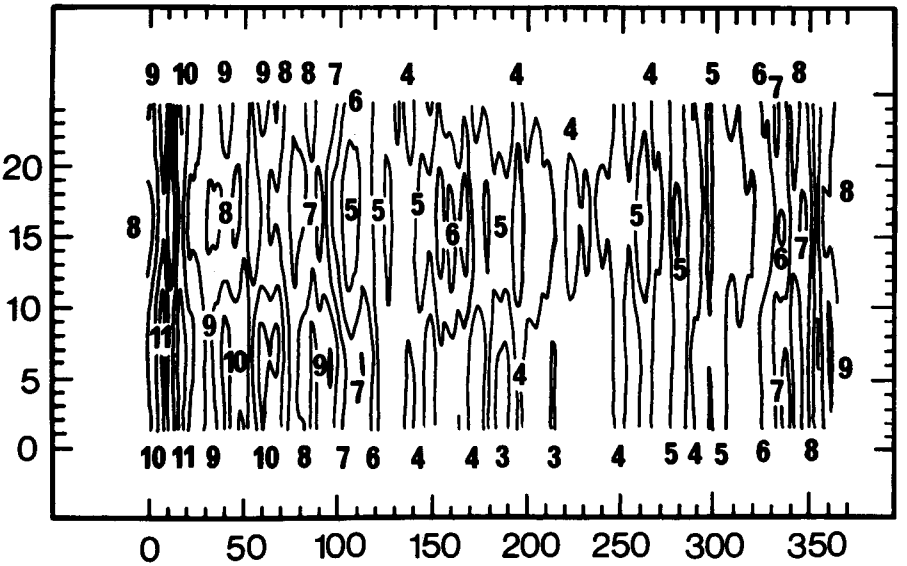
A**B****DAY OF YEAR**

FIGURE 2. The annual and diurnal pattern of air temperature at Schefferville, Quebec, based on hourly weather records from 1953 through 1970. Figure 2A shows the mean pattern with isopleths at 2°C intervals; Figure 2B shows the standard deviations about this mean pattern with isopleths at 1°C intervals.

annually from -24 to 16°C; the extreme temperatures recorded during 1953 through 1970 were -47.8 and 31.1°C. The mean temperatures change rapidly over the seasons and

show little diurnal variation except around the summer solstice. During this period, peak daily temperatures occur between 1300 and 1900 hours showing an expected lag behind

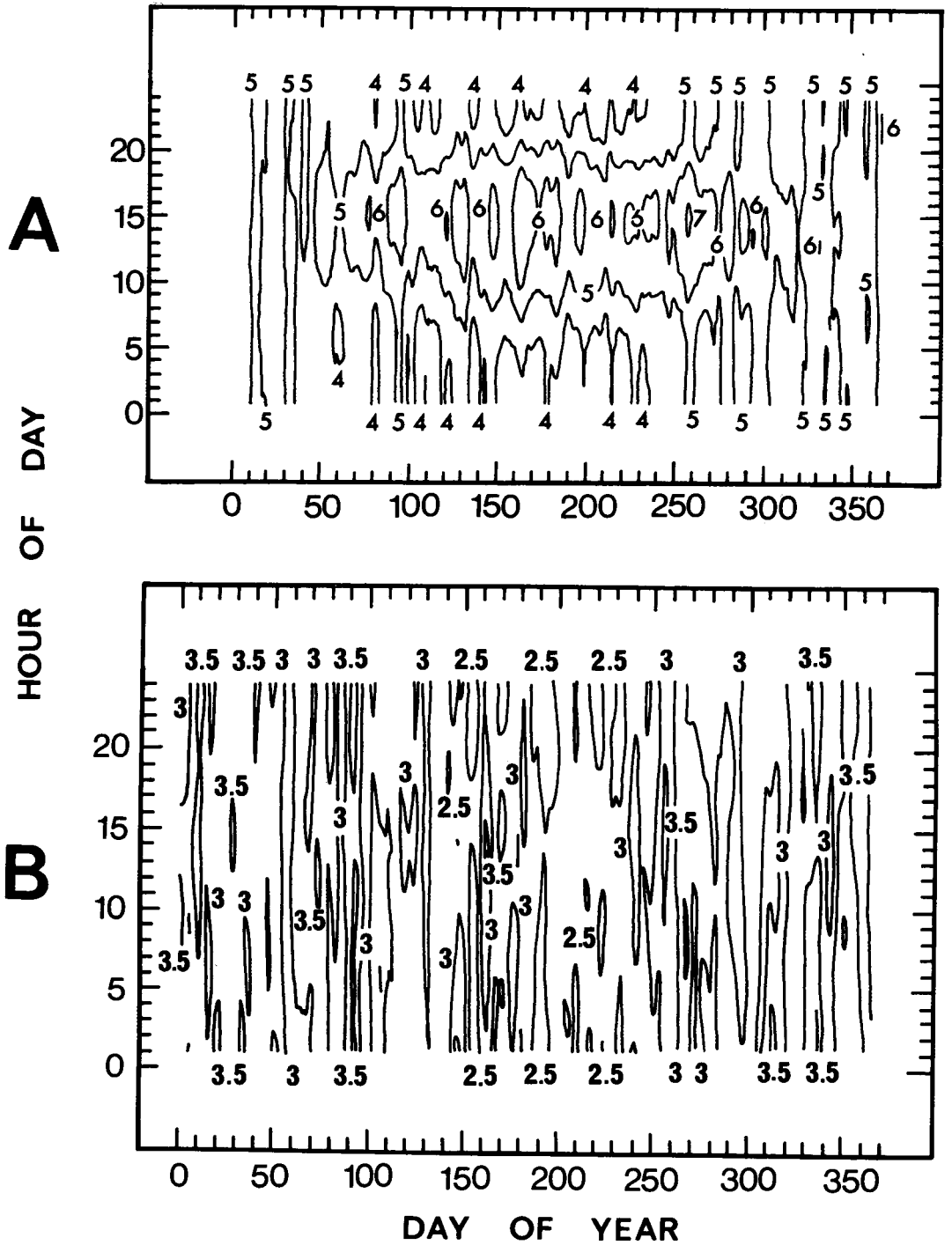


FIGURE 3. The annual and diurnal pattern of wind speed at about 12 m for Schefferville, Quebec, based on hourly weather records from 1953 through 1970. Figure 3A shows the mean pattern with isopleths at 1-m s^{-1} intervals; Figure 3B shows the standard deviations about this mean pattern with isopleths at 0.5-m s^{-1} intervals.

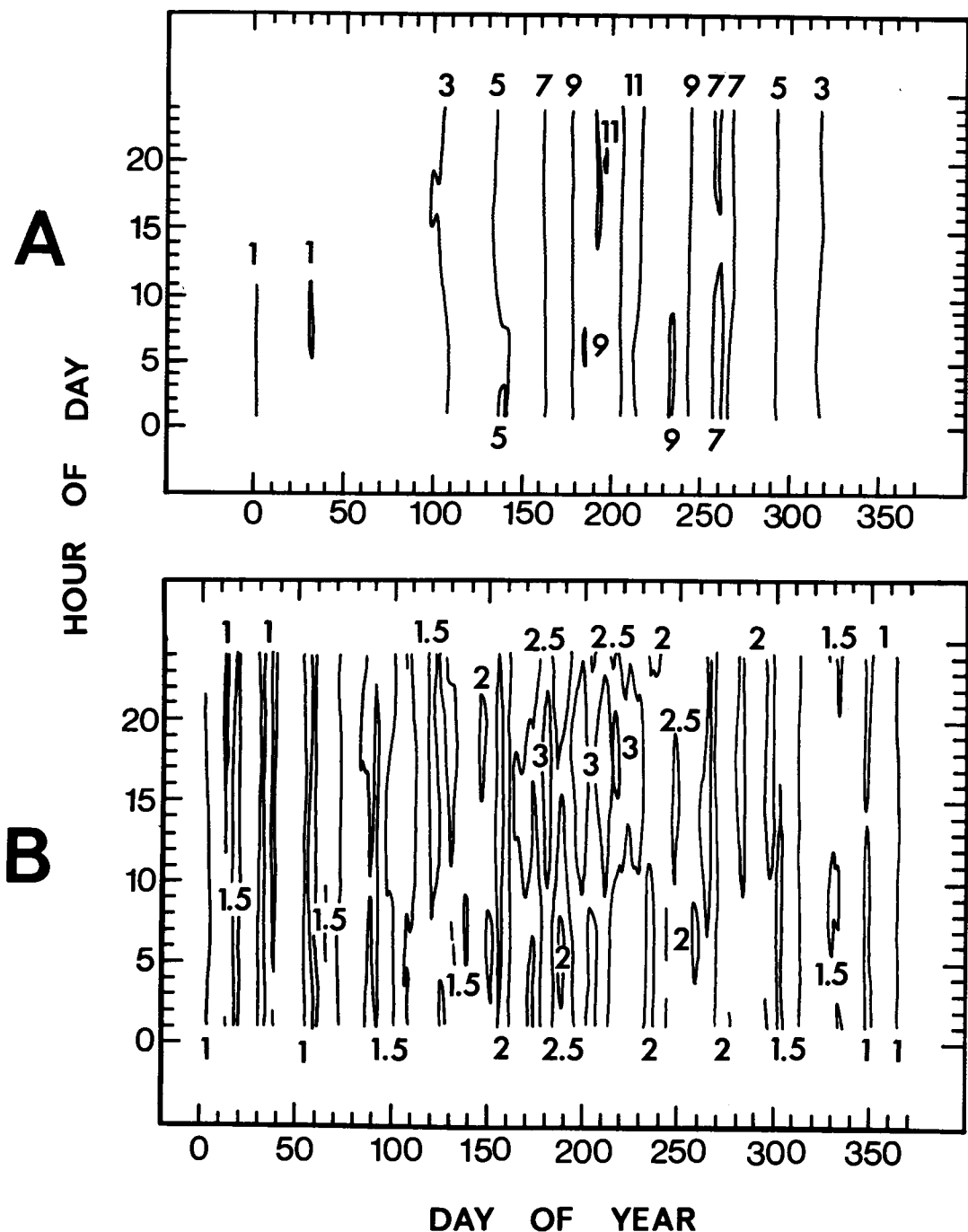


FIGURE 4. The annual and diurnal pattern of vapor pressure at Schefferville, Quebec, based on hourly weather records from 1953 through 1970. Figure 4A shows the mean pattern with isopleths at 2-mb intervals; Figure 4B shows the standard deviations about this mean pattern with isopleths at 0.5-mb intervals.

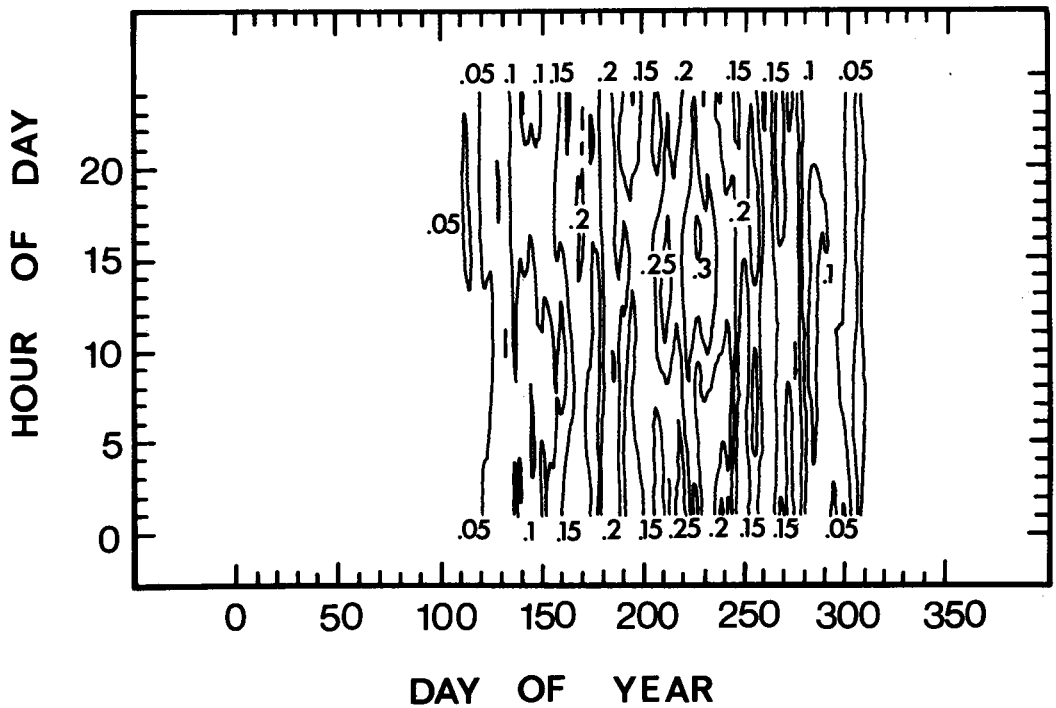


FIGURE 5. The annual and diurnal pattern for the probability of any hourly rainfall greater than .25 mm at Schefferville, Quebec, based on hourly weather records for 1953 through 1970. Isopleths are at 0.05-intervals.

peak solar radiation flux. Daytime mean temperatures first exceed 0°C about 1 April but predawn subzero temperatures prevail until 1 May. In fall predawn means drop to 0°C by early September and midday means follow soon thereafter. Temperature drops rapidly through October and November; temperature increases are more gradual in the spring with greater diurnal range. The variability about these mean patterns is least at night and from mid-June to early August. Winter has the most variable air temperature regime.

The wind regime (Figure 3) is relatively constant throughout the year. Wind speeds average about 4 m s^{-1} at night and increase to mean peak speeds of 6 to 7 m s^{-1} between 1000 and 1900 h. Extreme wind speeds of 0.0 and 26.8 m s^{-1} were recorded. Only the December and January wind regimes show no diurnal variation in wind speed. Variability about this pattern shows no diurnal trend and only a very weak indication of higher predictability

in April through July.

The vapor pressure regime (Figure 4) at Schefferville shows no diurnal pattern. During the cold winter months the air can hold very little water vapor; mean peak vapor pressures of 11 mb occur around the summer solstice when air temperatures are greatest. Variability around this mean pattern also peaks at this time. During 1953 through 1970 vapor pressure ranged from 0.0 to 25.9 mb.

The probabilities of measurable rainfall at Schefferville are greatest during July (Figure 5). Rains are almost equally likely at any hour. The rainfall probability declines steadily away from this midsummer peak; between November and April rain is unlikely. Rainfall was supplemented each year by means of 222 h of drizzle and 457 h of fog. Although snow can occur throughout the year at Schefferville (Tout, 1964), rainfall dominates the precipitation regime during the seasons of peak biological activity.

DISCUSSION

The graphical analysis presented here effectively condenses and displays information on the temporal structure of climate; the data required are readily available for many sites in North America (Parker and Anderson, 1969; U.S. Department of Commerce, 1969; Parker, 1972). More traditional methods such as synthetic indices, climate diagrams, tables, or simple bivariate graphs are useful in biological analyses of climatic patterns but only the contour plot can illustrate changes in a variable through the day and across the seasons simultaneously. The rapidity of seasonal change is inversely proportional to the distance between contours—the greater the distance, the more stable is the climatic regime.

These aspects of the graphs bear particularly on the problem of photosynthetic acclimation in arctic plants (Oechel, 1976). Plant photosynthetic response can change through the seasons but as yet we do not understand the environmental control of this phenomenon. Comparisons of acclimatory and climatic patterns may reveal relationships, for example, between the occurrence of acclimation and rates of seasonal climatic change. It is in studies such as this involving subtle relationships between climatic pattern and biological response that the use of contour graphs is especially appropriate.

The predictability of normal climatic patterns can also influence the evolution of biological responses. Photosynthetic acclimation cued by climatic events will not be selected for if current events do not reflect future events—climatic patterns have to be repeated year to year for acclimation to evolve. Contour graphs of the standard deviation can show the degree of variation about the mean climatic pattern. This graphical analysis complements

the predictability index of Colwell (1974) which is “essentially a measure of the variation among successive periods in the pattern of a periodic phenomenon.” For any two dimensional state-time matrix Colwell’s analysis gives an index of predictability scaled from zero to one; the index cannot presently accommodate the three dimensional day-hour-variable matrix discussed here. The graphical analysis illustrates the pattern of variation itself and also allows a subjective assessment of predictability on a simultaneous diurnal and seasonal basis. When it is important to consider the temporal pattern of variation in detail rather than condensing it to a single predictability measure, contour graphs of standard deviations are an appropriate analytic tool.

In conclusion, the contour graphs of means and standard deviations for climatic variables can illustrate the temporal structure of a climate. Such graphs provide a detailed basis for comparing climatic regimes in the analysis of adaptive strategies. The graphs may suggest climatic effects on seasonal and diurnal changes in biological responses. Analyzed variables need not be limited to the weather bureau records; any long-term synthetic variable such as estimated microclimate variables, plant productivity rates or animal population growth parameters could be graphed. As our understanding of adaptation to climatic regimes progresses, we may wish to employ more sophisticated techniques such as time series analysis (Platt and Denman, 1975) to specify particular aspects of the climate’s temporal structure. At present this simple graphical analysis may suffice to generate hypotheses about the relationship between climatic structure and biological responses.

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REFERENCES CITED

- Adams, W. P., Barr, W., and Nicholson, F. H., 1974: Annotated bibliography of the McGill Sub-Arctic Research Papers and Theses 1954-1974. *McGill Sub-Arct. Res. Pap.* 26. 98 pp.
- Barry, R. G., 1959: A synoptic climatology for Labrador-Ungava. *McGill Sub-Arct. Res. Pap.* 8. 168 pp.
- Colwell, R. K., 1974: Predictability, constancy, and contingency of periodic phenomena. *Ecology*, 55: 1148-1153.
- Gates, D. M., 1969: *Energy Exchange in the Biosphere*. Harper and Row, New York. 2nd edition. 151 pp.
- Idso, S. B. and Jackson, R. D., 1969: Thermal Radiation from the Atmosphere. *J. Geophys. Res.*, 74: 5397-5403.
- Kondratyev, K. Ya., 1969: *Radiation in the Atmosphere*. Academic Press, New York. 912 pp.
- Lechowicz, M. J., 1976: Environmental response structure of *Cladonia* lichens from contrasting climates. Ph.D. thesis, University of Wisconsin, Madison. (University Microfilms, Ann Arbor, Michigan, Diss. Abstr. 77: 3409.) 189 pp.
- List, R. J., 1971: *Smithsonian Meteorological Tables*. Smithsonian Institution Press, Washington, D.C. 6th edition. 527 pp.
- MacKay, D. K., and Cook, F. A., 1963: A preliminary map of continentality for Canada. *Geogr. Bull.*, 20: 76-81.
- McCloughan, C., 1961: Two weather observation sites: the old airstrip and the present McGill observatory location. *McGill Sub-Arct. Res. Pap.*, 11: 114-120.
- McCullough, E. C. and Porter, W. P., 1971: Computing clear day solar radiation spectra for the terrestrial ecological environment. *Ecology*, 52: 1008-1015.
- Monteith, J. L., 1973: *Principles of Environmental Physics*. Elsevier, New York. 241 pp.
- Oechel, W. C., 1976: Seasonal patterns of temperature response of CO₂ flux and acclimation in Arctic mosses growing *in situ*. *Photosynthetica*, 10: 447-456.
- Parker, J. E., 1972: *Guide to Canadian Climatic Data, Supplement No. 1*. Canadian Atmospheric Environment Service, Climatology Division Publication No. CLI-1-72, Toronto, Ontario.
- Parker, J. E. and Anderson, S. R., 1969: *Guide to Canadian Climatic Data*. Canadian Dept. of Transport, Meteorological Branch Publication No. CLI-6-69, Toronto, Ontario.
- Platt, T. and Denman, K. L., 1975: Spectral analysis in ecology. *Ann. Rev. Ecol. Syst.*, 6: 189-210.
- Pyldmaa, V. K. and Timanovskaya, R. G., 1972: Total radiation of the surface of the earth in various conditions of cloud cover. In Feygelson, Ye. M. and Tsvang, L. R. (eds.), *Heat Transfer in the Atmosphere*. Transl. from Russian as NASA TT F-790, 131-137.
- Sivkov, S. I., 1971: *Computation of Solar Radiation Characteristics* (transl. from Russian). Israel Program for Scientific Translations, Jerusalem. 185 pp.
- Thomas, M. K. and Anderson, S. R., 1967: *Guide to the Climatic Maps of Canada*. Canadian Department of Transport, Meteorological Branch Publication CLI-4-67, Toronto, Ontario.
- Thomas, M. K. and Parker, J. E., 1969: *Guide to the Climatic Maps of Canada, Supplement 1*. Canadian Department of Transport, Meteorological Branch Publication CLI-4-69, Toronto, Ontario.
- Thornthwaite, C. W., 1948: An approach to a rational classification of climate. *Geogr. Rev.*, 38: 55-94.
- Tout, D. G., 1964: The Climate of Knob Lake. *McGill Sub-Arct. Res. Pap.* 17. 236 pp.
- Troll, C., 1965: Seasonal Climates of the Earth. In Rodenwaldt, E., and Jusatz, H. J. (eds.), *World Maps of Climatology*. 2nd edition. Springer-Verlag, Berlin, 19-28.
- U.S. Department of Commerce, 1969: *Selective Guide to Climatic Data Sources*. U.S. Government Printing Office, Washington, D.C.
- Walter, H., 1973: *Vegetation of the Earth*. (Translation of *Vegetationszonen und Klima* by J. Wieser) Springer-Verlag, New York. 237 pp.
- Walter, H. and Lieth, H., 1960: *Klimadidgrammweltatlas*. Gustav Fischer, Jena.
- Wang, J. Y., 1961: The phyto-climate of Wisconsin 3. Moisture: normals and hazards. Part A. Rainfall. *Res. Rep.* 7A, Agric. Exp. Stat., University of Wisconsin, Madison. 64 pp.
- Wang, J. Y. and Suomi, V. E., 1958: The phyto-climate of Wisconsin 2. Temperature: normals and hazards. *Res. Rep.* 2, Agric. Exp. Stat., University of Wisconsin, Madison. 39 pp.
- Wilson, C. V., 1971: *The Climate of Quebec. Part One. Climatic Atlas. Climatological Studies 11*. Canadian Meteorological Service, Ottawa.

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