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SUMMER ACID RAIN EVENTS IN THE SCHEFFERVILLE, QUEBEC AREA

by

John E. Lewis and Bohdan Hrebenyk*

Introduction

A ubiquitous environmental ingredient of continuing industrialization is acid rain. Through the mechanism of long range atmospheric transport and the wet/dry deposition, pollutant loadings are occurring in remote areas with increased frequencies. The concern voiced for this problem and the effect on different ecosystems is well-documented (Beamish, 1976; Braekke, 1976; and Seliga and Dochinger, 1976).

Though the influence of acid rain on the ecology of a region is as yet imperfectly understood, increasing interest in the subject has spurred the Canadian government through the offices of Atmospheric Environment Service (AES) to establish the Canadian Network for Sampling Precipitation (CANSAP). While CANSAP includes some stations in northern Quebec, it is felt that the approach taken by AES tends to minimize information on the mechanism of pollutant transport. Specifically, the collection of rain is carried out over a period of approximately one month and then is analyzed as a single sample. While this may provide useful standards on which to base comparisons of total pollutant loading on the environment, the data collected in this manner will not serve to demonstrate the origins of the various chemical elements of the rainfall. Furthermore, studies conducted in the OECD pollution program (OECD, 1977) indicate that infrequent meteorological events

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are often associated with the episodic deposition of pollutants (5% of the wet days in sections of Scandinavia accounted for 30% of total wet sulphate deposits). It was felt that a program designed to study the interstorm variability of pollutant deposition would serve as an important contribution to the better understanding of acid rain phenomena in eastern subarctic Canada and would better aid in the evaluation of the CANSAP data. A pilot study was conducted to measure chemical constituents of precipitation and to describe the synoptic events which generated the rainfall for the Schefferville area of Nouveau Quebec during July and August 1978.

Methodology

Precipitation was collected in 9 in. diameter plastic rain gauges at two primary locations around Schefferville, (1) at the McGill Subarctic Research Station and (2) on Dolly Ridge, 3 miles east of the McGill Station. In addition, intermittent samples were collected at Iron Arm, approximately 12 miles east of the Station. During some storms, a sequence of precipitation samples were collected. The process of collection was rather tedious during this period because a wet/dry collector was not available; however, this situation has been remedied now.

The following procedures were maintained throughout the experiment:

(1) the rain gauges were washed with a weak acid solution then thoroughly rinsed with distilled H_2O after which the gauges were sealed;
(2) when a storm was forecast and the initial precipitation occurred, the rain gauges were set out for collection;
(3) as soon as precipitation ceased, a 250 ml sample was collected; the gauges returned to the laboratory where they were washed and sealed to await the next storm.

The precipitation samples were filtered and then the pH measured. The samples were stored at 4°C until the end of the summer at which time they were shipped to Montreal for further chemical analyses. Atomic absorption spectrophotometry was used to obtain concentrations of Na^{+}, Fe^{++}, Ca^{++}, and Mg^{++}, whereas nitrate (NO_3^{-}) and sulphate ($SO_4^{=}$) concentrations were measured with an automated calorimetric method (Technicon Auto-Analyzer).

Precipitation Analysis

Between July 1 and August 14, seven major storms occurred in the Schefferville region; however, due to various problems only five storms were analyzed - July 8, 16, 20, 27 and August 5-6. These five storms constituted ≃ 73% of the total precipitation during the study period.

TABLE ONE

Precipitation Chemistry for Rainfall Collected During July–August, 1978.

Class		Nitrate ppm	Sulfate ppm	pH(1)	Ca ppm	Na ppm	Fe ppm	Mg ppm	Total Precipitation mm
A-03 8/7	DR	0.05	<0.5	5.5	nd	.005	.02	.022	13.5
A-04 8/7	IA	0.02	<0.5	5.4	nd	nd	--	.005	
A-05 8/7	S	0.036	<0.5	5.5	nd	.010	.05	.003	11.0
A-06 16/7	DR	0.165	<0.5	4.8	nd	.15	.05	.011	16.0
A-07 16/7	IA	0.070	<0.5	4.7	nd	.025	.025	.006	
B-22 20/7	S 1st	0.014	<0.5	5.2	nd	.089	.07	.015	15.0
B-23 20/7	S 2nd	0.012	<0.5	5.1	nd	.013	.035	.006	
B-24 20-21/7	S Total	0.013	<0.5	5.8	nd	nd	.03	.018	14.5
B-25 20/7	DR	0.130	0.8	5.0	nd	.011	.05	.003	
B-26 20/7	IA	<0.001	<0.5	5.2	nd	.016	.06	.013	
C-02 27/7	S 1st	0.3	<0.5	4.5	nd	.01	.02	.006	10.6
C-03 27/7	S 2nd	0.16	1.6	4.8	nd	.013	nd	.014	
C-04 27/7	DR	0.008	1.8	4.9	nd	.01	.015	.010	8.1
D-18 5/8	S	0.008	<0.5	5.6	nd	.04	.02	.01	12.8
D-19 5-6/8	S	<0.001	<0.5	4.9	nd	nd	nd	.007	
D-20 5-6/8	DR	<0.001	<0.5	5.4	--	nd	nd	--	13.5
E-01 21-23/7	LS	<0.004	<0.5	6.0	--	--	--	--	
E-02 23/7	DR	<0.001	<0.5	5.6	--	--	--	--	
Distilled H_2O C-00 26/7		<0.001	<0.5	5.7	nd	nd	.02	nd	

S = Schefferville (Lab.)
DR = Dolly Ridge
IA = Iron Arm
LS = Laurentian Shield

nd = non-detectable

In only two of the five storms (July 16 and 27) was the pH less than 5. Table One is a list of the storm events and the precipitation chemistry. The storm of July 16 had a pH of ≃ 4.8 while on the 27th the pH was ≃ 4.6. Only the latter storm had values of sulphate concentrations above detectable limits of < 0.5 ppm. A comparison for the July 27th storm between the McGill Station site and Dolly Ridge shows sulphate concentrations of 1.6 ppm with 10.6 mm total precipitation for the Station to 1.8 ppm and 8.8 mm for Dolly Ridge. Nitrate concentrations had their highest values for these two storms with .16 ppm for July 16th and .3 ppm for the first part of the July 27th storm and .16 ppm for the second. Positive ions (Na^+, Ca^{++}, Mg^{++}, and Fe^{++}) generally displayed small concentrations for the five storms monitored. An ionic balance could not be calculated because of our failure to measure ammonium (NH_4^+) during this period.

Synoptic Storm Characteristics

Utilizing some of the early work of Barry (1959) for the Labrador region, we developed a preliminary synoptic classification of summer rain events for Schefferville. Ten years (1965-1974) of summer weather events were typed into four groups. Details of the classification will be published at a later date. From this synoptic classification, we isolated three

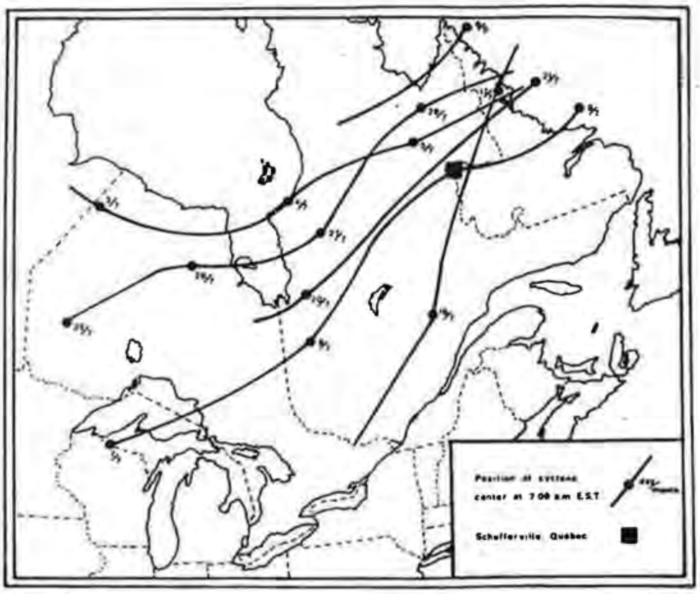

Fig. 1. Position of Cyclone Centers for the Storm Monitored

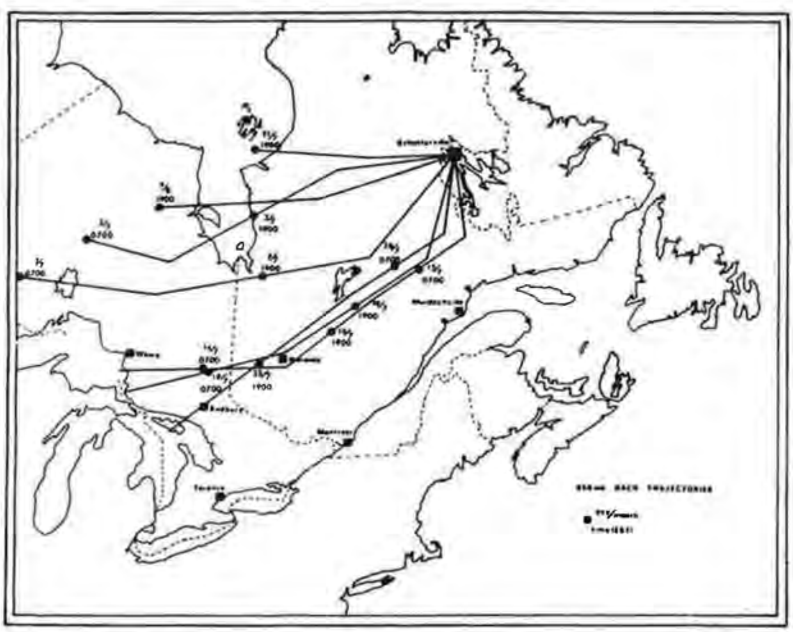

Fig. 2. 850 mb Back Trajectories Originating from Schefferville, Quebec

important storm parameters which we felt related to potential pollutant deposition episodes:

(1) the position of the cyclonic storm track in association with 850 mb back trajectories;
(2) antecedent synoptic conditions in middle and eastern North America; that is, 2 or more days of anticyclonic weather existing for this region;
(3) the number of hours the rain was occurring within the storm before it arrived at Schefferville.

These parameters are more distinctive for eastern Canada than the two main synoptic conditions which produce episodic wet deposition in northwestern Europe (Smith and Hunt, 1978).

Discussion

Figure 1 displays the storm tracks with their predominant SW-NE movement. The location of these storm tracks will impart an overall characteristic to the storm but each storm should be inspected in conjunction with air trajectories. For each of the storms, 850 mb back trajectories (Petterssen, 1956) were calculated as shown in figure 2. Most readers appreciate the assumptions and possible errors incorporated in the calculation of trajectories (Pack et al., 1978), but for this study the trajectories serve as a qualitative geographical indication of general source regions. The first trajectory segment is for 6 hours based on four surrounding stations, whereas succeeding segments are for 12 hours and the number of synoptic stations used in the calculations increase markedly towards the south.

The storm of July 16th developed farther east and the movement had a more northerly component than the 27th storm which proceeded slowly along a track from western Ontario across James Bay into middle Quebec. However, the 850 mb trajectories are very similar. Both these 850 mb trajectories have geographical approximation to two major point sources - Sudbury with emission over one million tons of sulfur a year (3500 tons/day) (Luis and Wiebe, 1976) and Noranda with 600 thousand tons of sulfur emitted a year. In addition, there are many possible point and area source contributions of SO_2 from the entire Great Lakes region. Figure 3 gives the location of the major point sources in eastern Canada and a section of the United States which are the most probable point sources of sulfur transport into Nouveau, Quebec. Also, the map points out the importance of area sources in N.E. United States, southern Ontario and southern Quebec as contributors to the sulfur emission problem.

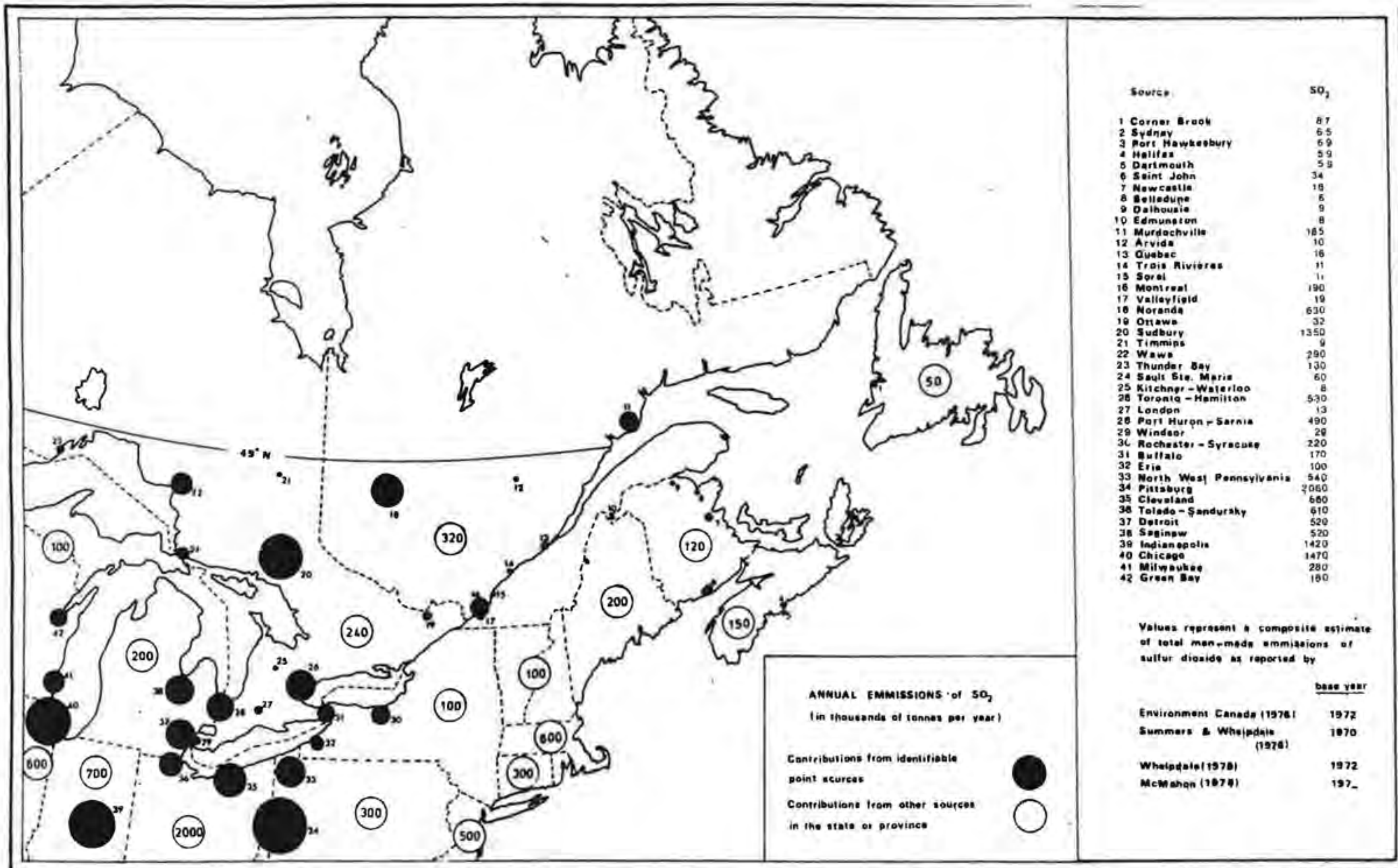

Fig. 3. Point and Area Annual Emissions of SO_2

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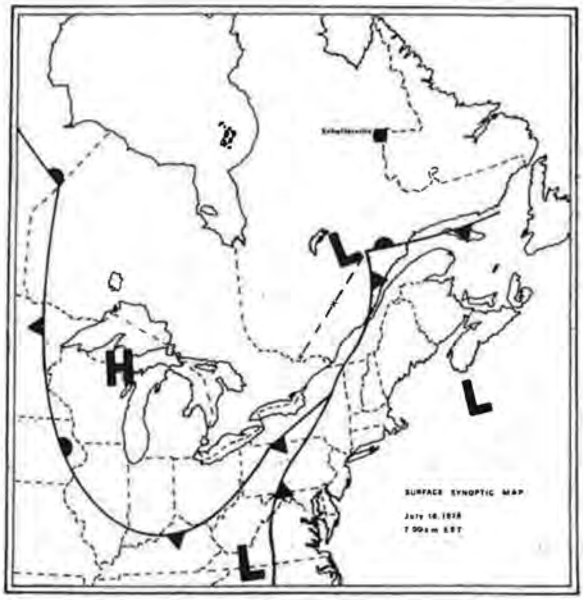
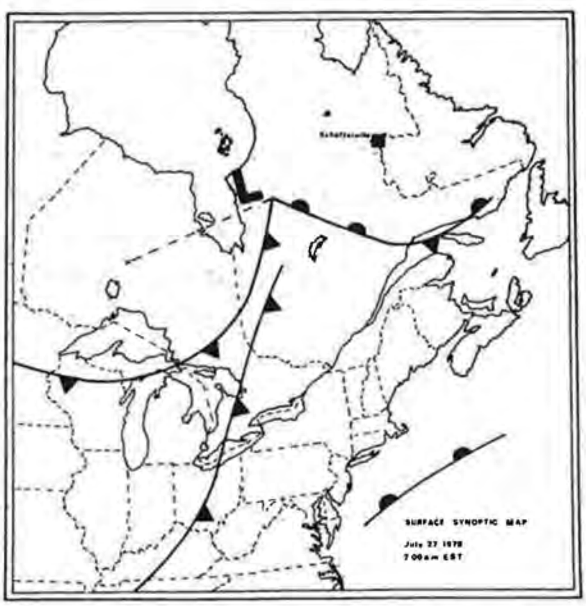


July 16, 1978



July 27, 1978

Fig. 4. Surface Synoptic Situations for two July, 1978, Storms

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SOME OBSERVATIONS ON THE CONSTANCY OF α IN THE EQUILIBRIUM MODEL FOR EVAPOTRANSPIRATION

by

John J. Drake*

Introduction

The combination model of evaporation, developed originally by Penman (1948), has been shown to be a powerful predictor of evaporative flux from many types of surface. In the usual definition,

$$LE = \alpha\, LE_s = \alpha \frac{s}{s+\gamma}(R_n - G) \quad (1)$$

and α for water and wet grass surfaces is generally approximately 1.26. Other vegetation types appear to show other values of α; for example, lichen = 0.95 (Rouse, Mills and Stewart, 1977), and Douglas fir = 1.05 (McNaughton and Black, 1973), but for each vegetation type the value is reasonably constant. McNaughton (1976a, 1976b) has shown that $\alpha \neq 1.0$ corresponds to the case where advection influences from upwind (and different) surfaces are important, and he has shown also that the rate at which α approaches 1.0 downwind from the leading edge of a given surface is a function of surface resistançes, net radiation, windspeed and other factors.

One formulation of the combination model is

$$LE = \frac{s}{s+\gamma}(R_n - G) + \frac{\rho Cp\,(Da - Do)}{r_a} \quad (2)$$

giving, for wet surfaces ($D_o = 0$), potential evapotranspiration as

$$LE_p = \frac{s}{s+\gamma}(R_n - G) + \frac{\rho Cp\ Da}{r_a}. \quad (3)$$

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In circumstances where no advection component is present ($D_z = D_o$), equilibrium evapotranspiration is given by

$$LE_s = \frac{s}{s+\gamma}(R_n - G). \tag{4}$$

Priestly and Taylor (1972) introduced α as defined by (1), and thus from (2)

$$\alpha = 1 + \left\{\frac{\rho Cp\ (D_z - D_o)}{r_a}\ \frac{1}{(R_n - G)}\ \frac{(s+\gamma)}{s}\right\}. \tag{5}$$

The usual form for r_a is

$$r_a = \frac{\{\ln[(Z - D)/Z_o]\}^2}{k^2\ u_z}. \tag{6}$$

It is therefore by no means obvious why, for a given surface, α appears to have a particular value, as it should vary with meteorological conditions (u_z, $[R_n - G]$ and D_z) and location with respect to other surfaces (from McNaughton's analysis); nor is it apparent why α has the numerical values that it does. Here I consider these questions.

The Constancy of α Under Measurement at a Site

The value of α does respond to local short-term meteorological conditions (e.g. diurnal, as shown by Bailey, 1977). The constancy of α is therefore logically on a daily basis, and this has been confirmed theoretically by McNaughton (1976a). A simple sensitivity analysis demonstrates why α has a stable mean value at a site.

The variables affecting α are u_z, $(R_n - G)$ and D_z directly and, through s, temperature. D_o affects α, but it is here assumed to be a surface property that is constant for a given surface. Davies and Allen (1973) have shown that the value for α for a drying soil surface can be modelled by a function dependent on surface soil moisture. The question of a variable D_o will be considered in the next section dealing with variations between surfaces. From (5) and (6)

$$\frac{\partial\alpha}{\partial(R_n - G)} = \frac{-\rho Cp\ \ (D_z - D_o)\ (s+\gamma)}{r_a\ \ \ s}\ \frac{1}{(R_n - G)^2}$$

$$= \frac{-(\alpha - 1)}{(R_n - G)} \tag{6a}$$

and simularly

$$\frac{\partial\alpha}{\partial D_z} = \frac{(\alpha-1)}{(D_z - D_o)} \tag{6b}$$

$$\frac{\partial\alpha}{\partial u_z} = \frac{(\alpha - 1)}{u_z}. \quad (6c)$$

Rouse and Stewart (1972) have shown that it is possible to approximate $s/(s+\gamma)$ well as $0.434 + 0.012T$, which leads to

$$\frac{\partial\alpha}{\partial T} = \frac{-(\alpha - 1)}{s/(s+\gamma)} \cdot 0.012. \quad (6d)$$

The root mean square error of α under measurement is thus

$$\Delta\alpha = (\alpha - 1)\ \mathrm{RMS}\ \left\{\frac{\Delta(R_n - G)}{(R_n - G)}, \frac{\Delta D_z}{(D_z - Do)}, \frac{\Delta u_z}{u_z}, \frac{0.012}{s/(s+\gamma)}\ \Delta T\right\}. \quad (7)$$

Almost all measurements of α have been undertaken in summer conditions, over relatively short runs of days and under settled weather conditions. The terms in the RMS function, taken as the ratio of standard deviation to the mean are, under such conditions, small (often < 0.1), and relatively constant. The range of departure of α from a particular mean value is therefore small and dependent on $(\alpha - 1)$. This is an important result because it demonstrates that α can be expected to be robust (rather than constant) for a given series of measurements, and that the robustness will increase as the mean value tends toward 1.0. Data shown in Table One, plotted in figure 1, show that this finding is supported. Equation (7) also shows that as $(D_z - Do)$ approaches zero, and consequently $(\alpha - 1)$ approaches zero, $\Delta\alpha$ becomes indeterminate. This may be a partial explanation for the fact that very few series of measurements to be found in the literature report α=1.0.

The Constancy of α for a Given Surface Between Sites

In the previous section the constancy of α in a particular series of measurements at a particular site was shown in fact to be robustness in the face of measurement and a consequence of relative insensitivity to meteorological conditions which are themselves relatively constant on a day-to-day basis. A similar argument can be advanced to explain why α for a particular surface (e.g. wet, short grass) is constant between sites, if it is assumed that D_o is a parameter set by the surface. Some studies of α referred to above (and particularly Rouse, Mills and Stewart, 1977) suggest that either α=1.26 when a surface is 'wet' (i.e. when D_o = 0) or that another particular value obtains when the surface is 'not wet': that is, for a particular vegetation canopy the transition between potential and non-potential evapotranspiration is relatively sudden. (e.g. Rouse, Mills and Stewart, 1977; McNaughton and Black, 1973). In other cases, however, as noted above the transition appears gradual (e.g. Davies and Allen, 1973).

TABLE ONE

Source	Mean α	Std. Error of Mean	Surface or Site
1. Marsh, Rouse & Woo (1979)	1.14	0.043	arctic soils
2. Davies & Allen	1.25	0.030	wet grass
3. Priestly & Taylor (1972)	1.34	0.05	CSIRO lysimeter
4. Priestly & Taylor (1972)	1.30	0.03	U. Wisc. lysimeter
5. Priestly & Taylor (1972)	1.08	0.01	Fluxatron
6. Priestly & Taylor (1972)	1.33	0.21	Wangara
7. McNaughton & Black (1973)	1.05	0.018	fir
8. Tanner & Jury (1978)	1.35	0.10	potatoes
9. Rouse, Mills & Stewart (1979)	0.91	0.028	new burn, α=0.91 data
10. Rouse, Mills & Stewart (1977)	0.97	0.018	old burn, α=0.97 data
11. Rouse, Mills & Stewart (1977)	0.95	0.022	upland lichen

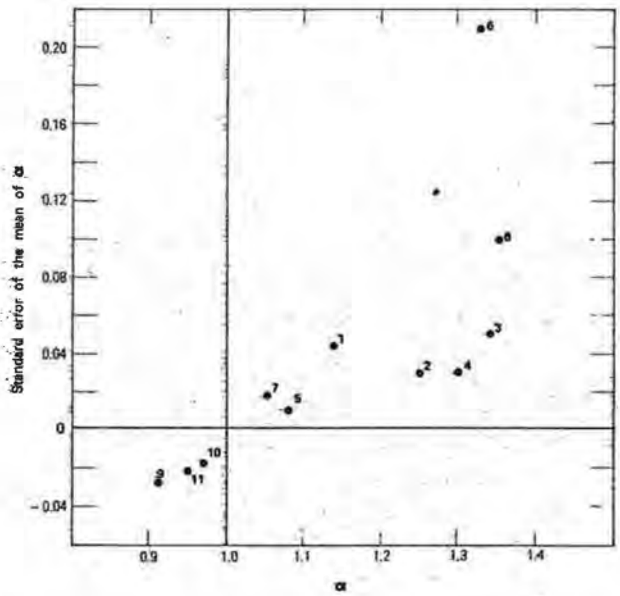

Fig. 1. Variation of the Standard Mean of α with α. Data points correspond to Table One

In view of these contrasting findings the case of potential evaporation ($D_o = 0$) will be examined to determine why α is almost uniformly reported to have the value of 1.26.

An alternate expression for α is

$$\alpha = \frac{s+\gamma}{s} \cdot \frac{1}{1+\beta} \qquad (8)$$

where

$$\beta = \frac{\gamma(T_z - T_o)}{(e_z - e_o)} \; . \qquad (9)$$

Figure 2 shows the values of α calculated from (8) and (9) under the conditions $e_o = e_{sat}(T_o)$. Table Two shows the locations for which α=1.26 in potential conditions has been reported. The table also shows mean air temperature and relative humidity (taken from standard government data) at meteorological stations close to those sites for the period in which measurements are stated to have been made. In all cases, measurements of α were limited to daytime values and so the temperature measure used in Table Two is the mean of the maximum and mean temperatures in an attempt to calculate a mean daytime temperature! The data points in Table Two are also plotted on figure 1.

For larger values of $T_a - T_o$ (e.g. -10°C and -15°C) the limits $1.2<\alpha<1.3$ encompass all data points except for that in southern Ontario, and in more northerly regions larger values of $T_a - T_o$ are to be expected. For the southern Ontario data point, values of $T_a - T_o$ may be smaller over a ventilated crop, and the data point lies in the range $1.2<\alpha<1.3$ for $(T_a - T_o) \simeq -5°C$. No great emphasis can be laid on the relationships between the zones and the data points shown in figure 2, but it serves to suggest that the reported values for α of 1.26 reflect the fact that most measurements have been taken at sites which show this as a mean value if $D_o = 0$ and $-5°C>(T_a - T_o) > -15°C$. Indeed, the range of air temperature and relative humidities for which this statement is true encompass most of the temperate zones where micro-climatological work on the Priestly-Taylor model is active.

Conclusion

This speculative discussion has suggested that the apparent constancy of α and the particular value of 1.26 often reported for potential conditions are a consequence of the robustness of α under short-term (usually summer) measurement periods at a given site together with the chance location of most such measurement sites in temperate or cool humid regions. Available data appear to support these suggestions, but rigorous testing is precluded

TABLE TWO

Mean Climatic Data for Studies Showing α = 1.26

Source	Site	Mo+	T_a(°C)*	RH_a(%)§
1. Davies and Allen (1973)	Simcoe, Ont.	6-9	22	65
2. Rouse, Mills and Stuart (1977)	Hudson Bay, Ont.	6	8	81
3. Rouse, Mills and Stuart (1977)	L. Athabasca, NWT	6	17	63
4. Marsh, Rouse and Woo (1979)	Resolute, NWT	7	6	83

+ Mo: month (Jan=1) in which observations were taken.
* T_a: mean over months shown of mean of monthly maximum and mean temperature.
§ RH_a: mean daytime relative humidity over months shown.

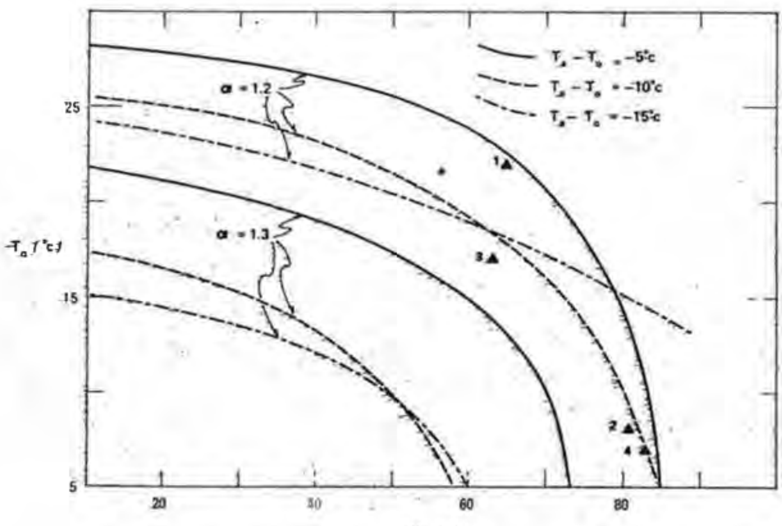

Fig. 2. Variation of Air Temperature (T_a) and Relative Humidity (RH_a) for which α lies between 1.2 and 1.3

by the lack of complete information about particular studies. The conclusions are not new, and the first especially is generally alluded to in particular studies. Nevertheless, the demonstration that most available studies share important common elements serves to warn against a too universal acceptance of the constancy or particular value of α.

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BIOMETEOROLOGICAL SEASONS: HOW SHOULD THEY BE DEFINED?

by

Simon M. Kevan*

Without being asked to consider the matter carefully most North Americans will say that the year has four seasons: Spring, Summer, Autumn - or if you prefer, Fall, and Winter. When asked to comment on graphs such as those presented in figure 1 there is a general tendency to point out the seasonal variations. This tendency prevades not only in the course of casual conversation but also throughout social and scientific literature. Often one finds references to the increased marriage rate of summertime; the decreased birth rate of wintertime; or the abnormal seasonal distribution of people born with certain types of characteristics such as the incidence of schizophrenia. In the same vane comments are made about the increased death rate of wintertime and the spring maximum to suicides. One cannot help but note the inclination to divide the year into its four conventional seasons. This inclination is not particularly surprising; after all, the belief that there are four seasons has pervaded western thought since the times of the ancient Greeks.

This idea of four seasons has been entrenched in our minds even more firmly by astronomers, who have established, without any regard for the inhabitants of the Southern Hemisphere, that the summer solstice takes place on June 21/22 and that the autumnal equinox occurs on September 22/23. Consequently, by their decree of all of humanity experiences summer between

* Simon Kevan is on the staff of the Geography Department at John Abbott College, Ste. Anne de Bellevue, Quebec. This article is an extended version of a paper presented at the Fourth Conference on Biometeorology held in Minneapolis, April 4-6, 1979.

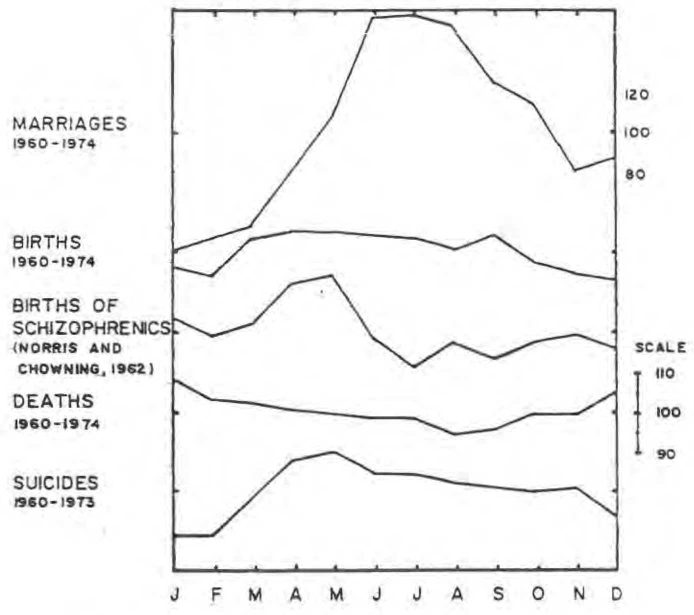

Fig. 1. The Seasonal Behaviour of Canadians
(data from Kevan, 1978)

those dates. One cannot dispute the fact that the dates of the solstices and equinoxes are of great importance to those who are interested in the relationship of the Sun to the Earth; however, it must be pointed out that by using this type of astronomic logic one discovers that summer is the longest season (93 days 15 hours) and that winter is the shortest season (89 days 1 hour). As one would be extremely hard pressed to find many Montrealers who believe that that is so, one must conclude that the astronomic definitions are not adequate.

For practical reasons, biometeorologists, especially human biometeorologists, have tended to reject the astronomic definitions of the seasons and have tended to accept (though sometimes with reservation) a definition of the seasons which is based on the months of a calendar. More often than not, biometeorologists have assumed the existence of four seasons and, as a result, have analysed their findings in terms of the occurrence of an event over various tri-monthly periods. Often winter is considered to be constituted of December, January and February, or sometimes of January, February and March. It matters little which is chosen, both suggest that winter is the shortest season.

Another problem associated with the standard calendar month definition of the seasons is that it assumes that a season begins on the first day of one month and ends on the last day of another. Anyone who listens to casual conversation concerning the seasons soon discovers that people do not believe this assumption either. It appears therefore that certain things must be established before one can comment on the seasonal distribution of any event. Firstly, one must establish how long the seasons are; and secondly, one must determine when they begin and when they end. It was to this end that I started to conduct research concerning people's perceptions of the seasons. I also wished to find out what types of criteria people used to define the seasons, as I thought that this might reveal a little more insight into the problem of defining the seasons. The purpose of this paper is to report my findings concerning those issues.

A review of literature indicates that very little attention has been devoted to the subject of defining the seasons. During the late 1930's a few geographers and natural scientists noted their dissatisfaction with the conventional definitions of the seasons, but their comments appear to have gone almost unnoticed (Kevan, 1979). Much more recently, Stanton Tuller (1975) produced an article in which he aired his objections to the astronomical definition of the seasons; however, unlike his predecessors, who attempted to redefine the seasons in terms of measures of ambient air temperatures, Tuller suggested a much more human approach to the matter. He determined the date of onset and the duration of the seasons in terms of a typical person's feelings of thermal comfort conditions. After taking into account normal air temperatures, humidities, windspeeds and solar radiation, he then defined the seasons in terms of the amount of clothing that would be necessary in order for a person to remain thermally comfortable at different times of the year. He defined winter as the time of year when three or more layers of clothing is necessary; spring and autumn as the time when a light suit is all that is required, and summer as the time of year when a minimal amount of clothing is all that is wanted.

It is worthwhile to outline some of Tuller's findings because they indicate the importance that geographical location plays on the date of onset and duration of the seasons. His examination of Canada's seasons show that springtime conditions are experienced first on May 1 in the interior regions of southern British Columbia. By May 15 nearly all of southern Canada is experiencing spring weather conditions; however, certain regions, such as the Maritime Provinces and the coastal areas of British Columbia have to wait

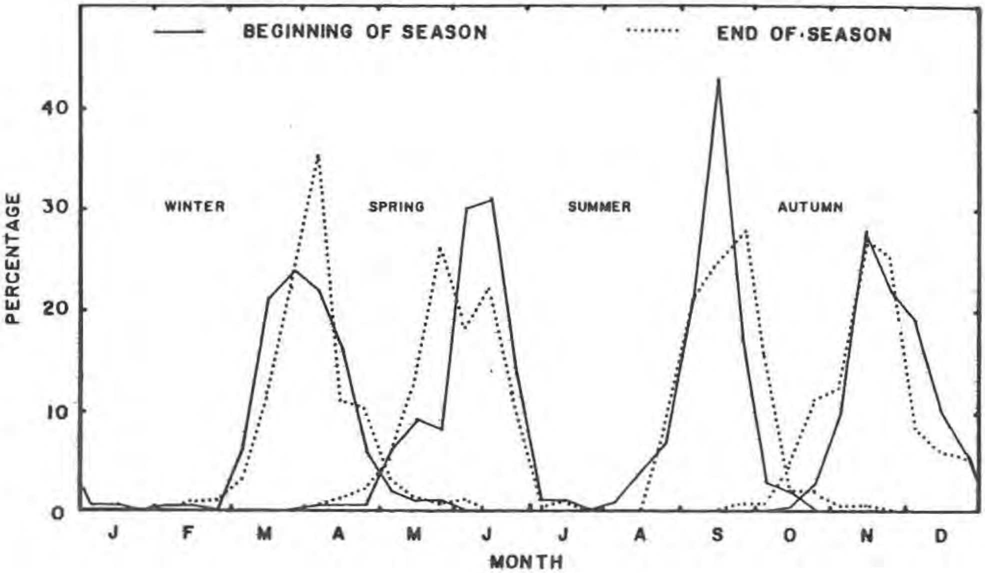

Fig. 2. The Perception of the Seasons by Montreal Area Students

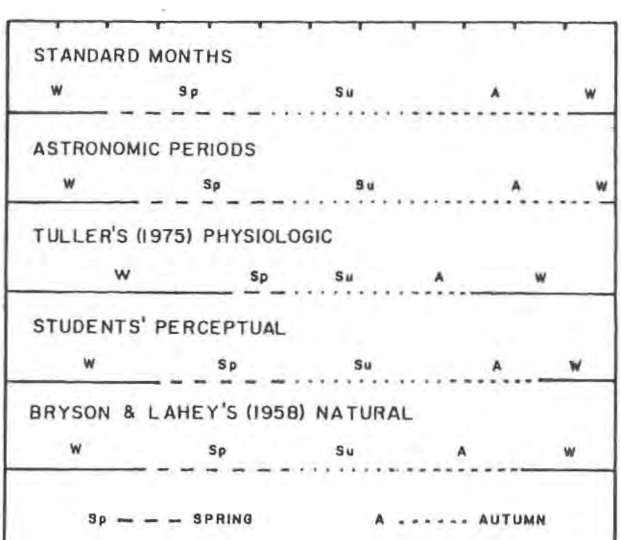

Fig. 3. The Length of Seasons According to Various Classification Systems

until June 1 for spring. Areas north of the treeline do not, according to this definition, regularly have spring weather conditions. The passage of summer conditions throughout Canada follows much the same pattern. Of course, the region of no summer is located substantially further south than the region of no spring. By defining the seasons in this way Tuller discovered that autumn was the shortest season and that winter was the longest. Even in the interior reaches of British Columbia winter lasts over 200 days. In Montreal the winter period works out to be about 225 days. It is unfortunate however that neither he nor any other research workers have applied this type of definition of the seasons to regions outside of Canada.

For the present study about 250 students were asked to fill out a questionnaire concerning the length and description of the seasons. It was stressed that the purpose of the questionnaire was to find out about their perception of the seasons, and that they were not to answer the questions in terms of what they thought they ought to answer. First they were aksed to state how many seasons they believed in. Then they are asked to indicate during the early, middle or late stages of which months these seasons began and ended. Finally they were asked to describe the seasons. Precaution was taken to make sure that only those students who had lived most of their lives in the Montreal region responded to the questionnaire.

It was no surprise to discover that most students believed that the Montreal region experiences four seasons; however, the belief was not held unanimously. About 15% of the students contested the notion of four seasons: 6% felt that Montreal had five seasons; slightly less that 4% suggested three seasons; just over 2% thought that Montreal had six seasons, and just less than 2% consider the possibility of three and a half seasons. The responses showed that nobody challenged the idea that Montreal experiences a winter and a summer; but what happens in between those seasons is open to much debate.

From Figure 2 it can be seen that the transitional period from one season to another takes about one month. From these data it is hard to determine which seasonal change is perceived to take place most rapidly and which takes place most slowly. The most likely candidates for these honours appear to go to the summer transition to autumn and the autumn transition to winter respectively.

By analysing the specific responses to the questions concerning the beginning and ending of the seasons it can be seen that the time for which there is greatest consensus of opinion is the beginning of autumn. Some 43% of the students noted that autumn starts in mid-September. The end of winter, taking place in late March (35%), also appears to be a fairly well defined period. It also can be seen that the beginning of summer is thought to take place either in early June (30%) or in mid-June (31%). There is much less agreement concerning the beginning and ending of the other seasons. All in all it can be seen that the seasons are not of equal prevalence in the minds of Montrealers, nor is it believed that they are of equal length. It is generally agreed that winter conditons exist during the months of January and February, and that summer conditions exist throughout July and most of August. Autumn is somewhat shorter and is confined mainly to the month of October. Spring, on the other hand, is not so well defined; it occurs in late April and early May, but there is considerable disagreement on this matter.

A comparison of these perceptual findings to the physiological seasons as determined by Tuller reveals some interesting points. Firstly, both studies indicate that winter is the longest season; but Tuller's classification system suggests that winter is longer than people perceive it to be. Secondly, both studies agree about the time and length of the summer period. Thirdly, both classification methods suggest that both spring and autumn are short periods; however, there is considerable disagreement over the matter of when these seasons take place. Tuller suggests that Montreal's spring is fairly well defined and that it takes place during late May and early June, whereas the students perceive spring to be a less defined period which takes place earlier in the year. Tuller's method also indicates that autumn is the shortest season in Canada, but the perceptual findings do not support that idea.

A perusal of the description of the seasons as given by the student helps to explain why the perceptual and comfort classification differ. The descriptions revealed very few references to either clothing requirements or thermal sensations. In fact, out of the hundreds of comments which were made these factors were mentioned but a handful of times. This insensitivity to thermal conditions could very well be a product of our thermally protected lifestyle. It would be of considerable interest to find out how people who live in much less protected environments would respond.

One thing which did become exceptionally clear from the descriptions that were written was that meteorological conditions are considered to be a major determinant for defining the seasons (see Table One). It can be seen that certain types of weather conditions are associated with the various seasons; however, it appears that weather conditions alone do not make the

TABLE ONE

The Seasons and Their Associations (after Kevan, 1979).

Season	Meteorological Conditions	Biological Conditions	Human Reactions
Spring	Warming temperatures Snow melting Sun	Growing of plants	Flood prevention Odours
Summer	Unpleasant heat Humidity Showers	Plants blossom Green leaves	Relaxation Outdoor life
Autumn	Rain Cool temperatures Frost	Colourful leaves Falling leaves	Unpleasant (Melancholy)
Winter	Snow Very cold temperatures Very low humidity Storms	Lifelessness	Skiing Apathy

seasons. The seasons also have their own biological and human connotations. It was this realization which led me to conclude that biometeorologists require a much more meaningful definition of the seasons. It was in this round about manner that I came to a rather self-evident, though seldom mentioned, conclusion: Obviously, if biometeorologists, especially human biometeorologists, wish to examine and comment upon the relationship between atmospheric processes and seasonal biological activity, then they ought to examine these relationships in terms of meteorologically defined seasons.

Another literature search revealed that several attempts have been made to define the seasons in terms of prevalent meteorological conditions (Barry and Perry, 1973). Particularly noteworthy for North American biometeorologists are the works of Bryson and Lahey (1958), Barry (1967) and Bryson and Hare (1974). A comparison of the natural meteorological seasons as defined by Bryson and Lahey to the other types of definitions of the seasons is shown in figure 3. One cannot help but be surprised at how closely the perceptual seasons resemble the natural seasons. The only discrepancy between the two systems of classification occur with the definition of autumn which is perceived to start a little later and to be a little shorter than the meteorological definitions would have it.

It is hard to know whether this uncanny resemblance is a product of an unconscious realization by people concerning the times of year when major meteorological changes are taking place, whether it happens to be a spurious coincidence; or whether it is a little of both. Much more research would have to be conducted in various parts of the world before this matter can be resolved.

Regardless of whether or not perceptual seasons just happen to be coincidental with the natural seasons of Bryson and Lahey, this study has indicated that biometeorologists should try to take into account the seasons as they are experienced by their subjects, something which seldom has been attempted. I believe that the biometeorologists task would be made much easier if those interested in seasonal phenomena would include in their discussion a note on the general synoptic conditions which prevail during the different times of the year in the area in which they have conducted their study, and it is on that note that I wish to end this presentation.

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