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CLIMATOLOGICAL BULLETIN

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FOREWORD

With this number, CLIMATOLOGICAL BULLETIN enters its fifth year of publication. The occasion has been used to introduce changes in its format and date of publication. The former change has been to reduce the page size and to present the BULLETIN in a style which tends, in appearance, more towards a normal printed form than the mimeographed style of preceding numbers. No attempt has been made, however, to create a regular printed type of journal. Apart from the cost involved, it is felt that the BULLETIN serves a useful purpose in being produced rapidly by photographic means. Thus, it can continue to operate as a medium for short articles, progress reports on research as it develops, and comments on experiments which, while useful in themselves, are not yet in a form which makes their results attractive to the regular, established revues.

The change in date is a matter of prudence and practicability. The BULLETIN will now appear as being published in April and October, instead of January and July. Experience has shown that the organisation of an academic year, and the concentration of field work in the summer, have combined to make the distribution of the BULLETIN close to January and July almost impossible. Indeed, for the past two years the effective distribution months have tended to be May or June on the one hand and November on the other. Recognising this, the harassed editor has settled for April and October on the cover page!

Readers are again reminded that offers of contributions from outside the Department of Geography at McGill University are welcome. These should conform to the style and objectives of the BULLETIN. Reports on graduate student research in progress or completed are particularly welcome, preferably submitted through a supervisor with, if possible, an indication of whether or not a financial contribution towards publication costs might be available. The BULLETIN costs about $10 a page to produce and help towards articles at this rate would be appreciated but is not necessarily essential. New subscriptions continue to come in, and the total is now about 300, of which 50-60 are outside North America. Thus the BULLETIN is slowly becoming recognised as useful, and offers a potentially rapid means for making known the work going on in climatology in different graduate and research institutions.

B. J. Garnier
Editor

THE CONCEPT OF EQUILIBRIUM EVAPOTRANSPIRATION

by

R. G. WILSON*

The balances of water and energy on land surfaces are both dependent upon the process of evapotranspiration. Despite the significance of this process, an operational evapotranspiration model for general application has not yet been developed. A major deterrent in this regard is the complexity of the process, since it involves interactions between the atmosphere, the vegetation, and the soil.

Only atmospheric influences are considered in the concept of potential evapotranspiration. In this case the vegetation and soil influences are eliminated by considering only turgid vegetation which provides complete ground cover and which has an unrestricted water supply. The first theoretical potential evapotranspiration model was developed by Penman (1948). Tests of the Penman model, with an improved wind function, have shown that it accurately predicts both hourly and daily values of evapotranspiration when the surface is wet (Davies and McCaughey, 1968). However it fails when the surface becomes dry.

Models applicable to any surface moisture condition have recently been proposed by Monteith (1965) and Tanner and Fuchs (1968). However neither of these are sufficiently developed for general application. The Monteith model requires the measurement or prediction of a surface resistance to the diffusion of water vapour. No satisfactory method has yet been devised to determine the resistance without first measuring the evapotranspiration rate (Szeicz and Long, 1969). The Tanner and Fuchs model requires a measurement of the surface temperature, a parameter which is nearly impossible to define for a vegetation cover.

The three models mentioned thus far are variants of the general "combination" model, which incorporates both the energy balance and the aerodynamic approaches to the evaluation of evapotranspiration. An instructive derivation of the combination model equation arises from a consideration of the energy exchanges occurring in an isolated parcel of air resting over an

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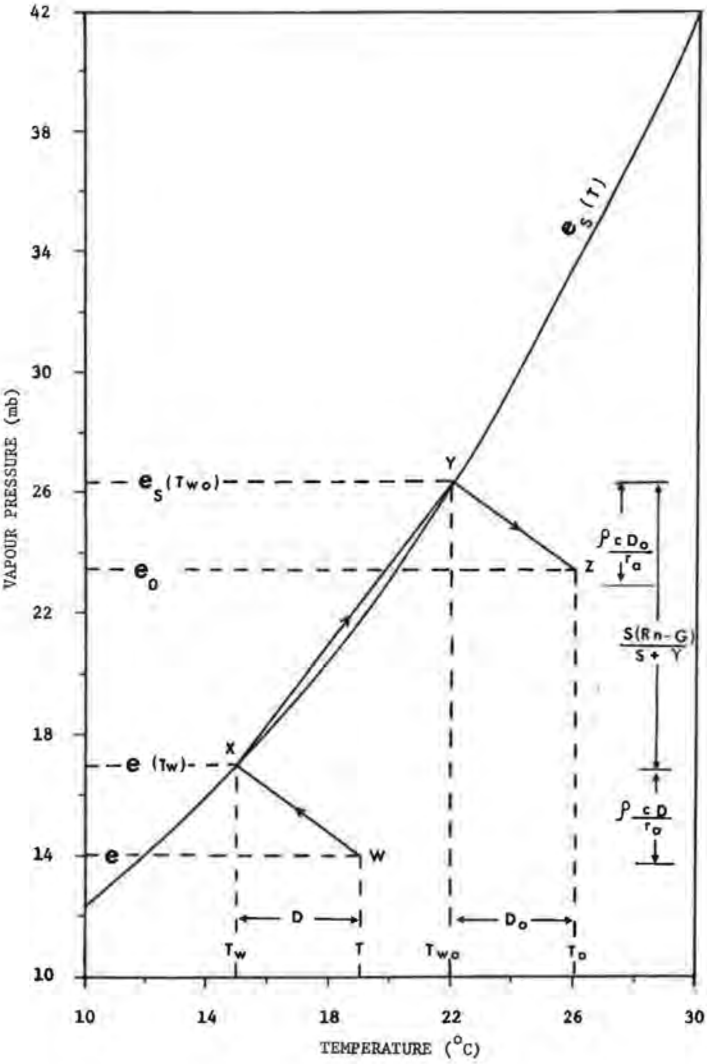

Fig. 1 Graphical Illustration of the Natural Evaporation Process.

evaporating surface. The derivation which follows and the graphical illustration of the process (Fig. 1) are essentially the same as those presented by Monteith (1965), but are included here for the specific purpose of explaining the concept of equilibrium evapotranspiration.

The natural evaporation process, and the resulting energy exchanges, are illustrated in Fig. 1. Evaporation of water into initially unsaturated air (point W) may proceed until saturation occurs (point X). The heat required for the conversion of the liquid water to vapour is provided by the sensible heat contained by the air. The resulting decrease in the sensible heat content, ΔQ_H, is represented by

$$\Delta Q_H = \rho \, cD \tag{1}$$

where ρ is the air density, c is the specific heat of air at constant pressure, and D is the temperature decrease in the air, which in this case is equal to the wet-bulb depression. If r_a is the time required for 1 cm^3 of air to exchange heat with 1 cm^2 of the water surface, then the latent heat flux, LE_1, is

$$LE_1 = \frac{\rho cD}{r_a} . \tag{2}$$

Evaporation may continue beyond this point only if there is an addition of heat to the parcel of air. This will result in an increase in both the air temperature, T, and the vapour pressure, e, with corresponding increases in the sensible heat content, Q_H, and the latent heat content, Q_L, of the air. These are related (Brunt, 1939) by

$$\frac{de}{dQ_L} = \frac{\gamma dT}{dQ_H} \tag{3}$$

where γ is the psychrometric constant (γ = 0.66 mb $^{\circ}C^{-1}$). Since the air is saturated at point X, e may be replaced by the saturation value, e_s. In this case, small changes of vapour pressure and temperature are related by

$$S \, dT = de_s \tag{4}$$

where S is the slope of the saturation vapour pressure - temperature curve at the current air temperature. Rearranging equation (3) and substituting e_s for e,

$$\frac{de_s}{dT}\,dQ_H = \gamma dQ_L \tag{5}$$

and substituting equation (4) into (5) yields

$$S\ dQ_H = \gamma dQ_L\ . \tag{6}$$

Adding and subtracting S dQ_L on the right hand side of (6) and rearranging terms gives

$$S\ dQ_H = (S + \gamma)\ dQ_L - S\ dQ_L \tag{7}$$

and hence

$$dQ_L = \frac{S(dQ_H + dQ_L)}{S + \gamma}\ . \tag{8}$$

The term dQ_L for unit time is equal to the latent heat flux, LE_2, during the saturated portion of the evaporation process. Also, ($dQ_H + dQ_L$) represents the total heat gain by the parcel, and in a natural situation this heat would be provided by the difference between the net radiation, Rn, and the soil heat flux, G, so that

$$LE_2 = \frac{S(Rn - G)}{S + \gamma}\ . \tag{9}$$

The temperature and vapour pressure conditions in the air parcel might now be represented by point Y in Fig. 1, which corresponds to the wet-bulb temperature of the air at a natural evaporating surface. If the air at the surface was not saturated, then its condition might be represented by point Z. To reach this point from Y, latent heat must be released from the air at a rate given by

$$- LE_3 = \frac{\rho c D_o}{r_a} \tag{10}$$

where D_o is the wet-bulb depression in the air at the surface. The total latent heat flux, LE, for the path W to Z is then the sum of the three components, which may be written as

$$LE = \frac{S(R_n - G)}{S + \gamma} + \frac{\rho c(D - D_o)}{r_a} \tag{11}$$

This is the form of the combination model presented by Slatyer and McIlroy (1961). In principle, S should be calculated at the mean of the wet-bulb temperatures in the air and at the surface. However, temperatures at a natural evapotranspiring surface are difficult to measure accurately, so an approximation is required. As indicated in Fig. 1, the dry-bulb temperature of the overlying air will usually be close to the mean wet-bulb temperature, and so it may be used to calculate the value of S. This can be accomplished by using an approximate solution for S which was presented by Dilley (1968). Incorporating the assumption that $T = (Tw_o + T_w)/2$, S may be calculated as

$$S = \frac{de_s}{dT} \simeq \frac{25{,}029}{(T+237.30)^2} \exp \frac{17.269T}{T+237.30} . \tag{12}$$

The formulation for LE presented in equation (11) is not practical for general use due to the difficulty of measuring D_o, but it is instructive because it separates the basic energy sources. The first term on the right-hand side represents the net amount of radiant energy directly expended on evapotranspiration, while the second term represents the energy used from the atmosphere for this purpose. It is the second term which is principally responsible for evapotranspiration differences between surfaces of different wetness. When a surface is wet or moist, the air close to it is saturated ($D_o = 0$). This is the potential evapotranspiration condition which is considered in the Penman (1948) model. However when the water supply to the surface is restricted, D_o acquires a finite value and the actual evapotranspiration rate will be less than the potential. Recent combination model developments by Monteith (1965), Tanner and Fuchs (1968), and Fuchs et al. (1969) have in fact been attempts to eliminate D_o in favour of other parameters which may be more easily measured or estimated.

Slatyer and McIlroy (1961) considered the special and apparently limited case when the two depressions are equal, thereby eliminating the atmospheric term. This reduces equation (11) to

$$LE = \frac{S(Rn - G)}{S + \gamma} . \tag{13}$$

In this case the evapotranspiration rate is simply a function of the available radiant energy and the air temperature. The approach is essentially an energy balance one, with the Bowen Ratio equal to γ/S.

Monteith (1965) and Tanner and Fuchs (1968) have drawn attention to the fact that equation (13) describes the evapotranspiration which would occur in a saturated atmosphere. This is the simplest case in which the depressions are equal, because both are equal to zero. However it is possible that the depressions might have finite values and still be equal or nearly equal, in which case equation (13) would remain valid or stand as a good approximation. Slatyer and McIlroy (1961) considered that equality of the depressions occurred when the surface and the overlying air had adjusted to one another, and so they suggested that the conditions described by equation (13) should be referred to as "equilibrium" evapotranspiration.

The equilibrium model is appealing because of its simplicity. The parameters Rn, G, and T are easily measured or estimated and the weighting factor $S/(S + \gamma)$ may be calculated as an integral part of a computer programme or it can be determined from a table (see Table One). Use of the model is warranted, however, only when $D = D_o$. This situation is not likely to occur either when the surface is wet ($D \gg D_o$) or when it is very dry ($D \ll D_o$). It seems probable that there must be a middle range of moderately dry surface conditions when $D \approx D_o$ and the equilibrium estimates will closely approximate the actual evapotranspiration rate.

The accuracy of the equilibrium model and the moisture limits within which it may be applied are currently under investigation by the author, and the results to date are extremely encouraging. The model is only an approximation of the actual evapotranspiration process, so a certain degree of error must be expected in the estimates. Consequently the problem has essentially become one of defining those limits within which the estimates are reasonably accurate. Maximum errors of ± 10 percent of daily evapotranspiration would probably be acceptable for most potential hydrological and agricultural applications (Penman, 1956 ; Tanner, 1960). There are strong indications that the equilibrium model satisfies these demands for quite a wide range of moderately dry surface conditions when the actual evapotranspiration rate is less than the "potential" rate. In a recent study, Denmead and McIlroy (1970) compared hourly values of equilibrium evapotranspiration with measured values. The data exhibited a moderate degree of scatter and the model produced underestimates at high evapotranspiration rates. The authors suggested that the equilibrium rate is probably approached closely on only a few occasions, but they also expected that departures from the actual rate would rarely be extreme. These results and conclusions provide further evidence of the potential capabilities of the equilibrium model, but they clearly indicate the necessity of defining the limits within which its use is justified. If these can be established, the equilibrium model may prove to be the first operational method of accurately predicting short-term evapotranspiration losses for drying surfaces.

TABLE ONE

Values of $S/(S + \gamma)$ for various temperatures

T(^{o}C)	$S/(S + \gamma)$	T(^{o}C)	$S/(S + \gamma)$
2	0.433	22	0.709
4	0.464	24	0.731
6	0.495	26	0.751
8	0.525	28	0.769
10	0.555	30	0.787
12	0.584	32	0.803
14	0.611	34	0.818
16	0.638	36	0.832
18	0.663	38	0.844
20	0.687	40	0.856

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SOIL HEAT FLUX DIVERGENCE IN A DEVELOPING CORN CROP

by

R.G. Wilson and J.H. McCaughey*

1. Introduction

The energy balance framework is frequently used to assess evapotranspiration losses from vegetated surfaces. This approach is taken in Bowen Ratio measurements and in combination model predictions of the water vapour flux. The balance of energy can be written as

$$Rn - G = LE + H \qquad (1)$$

where Rn is the net radiation, G is the soil heat flux, LE is the latent heat flux, and H is the sensible heat flux. An investigator using either the Bowen Ratio or the combination model approach must determine the quantity (Rn - G). Rn is clearly the most important term since it represents the total energy input in the balance. On the other hand, G is frequently the least important of the three energy dissipation terms in equation (1). Measurements have indicated that it usually represents only 5 to 10 percent of Rn for completely vegetated surfaces (Tanner and Pelton, 1960; Sellers, 1965, p. 111; Davies and McCaughey, 1968; Wilson, 1970). This proportion generally increases with a greater exposure of bare soil; for example, Decker (1959) found that soil heat flux under short corn plants represented 15 percent of Rn. The importance of this amount of energy should not be overlooked. Good evapotranspiring conditions are indicated when the Bowen Ratio ($\beta = H/LE$) has a value of $\beta = 0.2$. In a situation where $\beta = 0.2$ and $G = 0.15$ Rn, then $H = 0.14$ Rn. Thus, the fluxes of soil heat and sensible heat are approximately equal. Under these or similar conditions, G should be measured with the same precision as the other energy terms. Unfortunately many soil heat flux measurements have been made

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without proper consideration of the accuracy of the determination.

The flux of heat into a soil is given by

$$G = - \lambda \frac{\partial T}{\partial Z} \tag{2}$$

Where λ is the thermal conductivity of the soil and $\partial T/\partial Z$ is the vertical gradient of soil temperature between the surface and depth Z. Equation (2) is infrequently used in field investigations because of the difficulties experienced in measuring λ and $\partial T/\partial Z$ near the soil surface. These problems are eliminated by the use of heat flux transducers. Frequently the transducers are placed about 1 or 2 cm below the surface, and the recorded flux is assumed to be equal to the flux occurring at the surface. However, this procedure may introduce significant errors in the estimates of G. A flux plate should not be installed so close to the surface because it interferes with moisture flow and thereby creates sampling dissimilarities. Another sampling problem may also be created by surface heterogeneities. These problems may be overcome by placing the plate deeper in the soil, but then errors may be caused by soil heat flux divergence between the plate and the soil surface.

As a result of these considerations, it is usually recognized that the most practical and accurate method of determining the heat flux at the surface involves measuring the flux at a depth of 5 to 10 cm and then accounting for the heat flux divergence between the plate and the surface (van Wijk, 1965; Sellers, 1965, p. 131; Fuchs and Tanner, 1968). In this case the surface flux, G_o is given by

$$G_o = G_Z + \Delta G = G_Z + C \frac{\Delta T}{\Delta t} Z \tag{3}$$

where G_Z is the flux at depth Z and ΔG is the heat flux divergence between depth Z and the surface, C is the heat capacity of the soil between depth Z and the surface, and $\Delta T/\Delta t$ is the change of the mean temperature of the layer per unit time.

The heat capacity can be written as

$$C = C_m\chi_m + C_o\chi_o + C_w\chi_w + C_a\chi_a \tag{4}$$

where C_m, C_o, C_w and C_a are the heat capacities of mineral and organic matter, water, and air, respectively, and χ_m,χ_o, χ_w,and χ_a are the corresponding volume fractions of each constituent. The heat capacity of air is so small compared to the others that the term $C_a\chi_a$ may be safely neglected. De Vries

(1963) suggested average values of $C_m = 0.46$ and $C_o = 0.60$, whereas $C_w = 1.0$ cal cm^{-3} $^oC^{-1}$, so that equation (4) reduces to

$$C = 0.46\ \chi_m + 0.60\ \chi_o + \chi_w \tag{5}$$

The values of χ_m and χ_o will remain constant for a given location, so it is necessary to routinely measure only χ_w.

2. Experimental

Soil heat flux was measured in a series of energy balance investigations at the Simcoe Horticultural Research Station in Southern Ontario during the summer of 1969. The research programs have been described earlier by Davies, Rouse, and Oke (1970). All measurements were conducted in a large field of sweet corn (Zea Mays: horticultural variety Seneca Chief) which was planted in 1m rows oriented in a NW - SE direction (Fig. 1a). The growth curve during the study period in July and August is shown in Fig. 1b.

The soil heat flux instrumental array (Fig. 1a) comprised three soil heat flux plates and a number of thermocouples. The soil heat flux plates (Middleton and Pty Ltd.) were installed at a depth of 5 cm and were connected in series to give a spatial average of the flux at that depth. The mean soil temperature between the surface and 5 cm depth was measured with thermocouples connected in series. Individual junctions were mounted on 3/4" wooden dowels and 15 cm of thermocouple wire were wrapped around the dowels at each measurement level to eliminate conduction errors. The mounted thermocouples were placed at depths of 0.5, 1.5, 2.5, 3.5, and 5.0 cm. The common reference junction was installed at a depth of 1.5 m and the temperature at that depth was monitored by a separate thermocouple which was referenced to an ice-water bath. The signal from the flux plates was continuously recorded on a Honeywell Electronik 194 strip chart recorder and was integrated with a planimeter to give hourly values of G_5. All temperature signals were measured and recorded by a Solartron data system, and hourly values of $\Delta T/\Delta t$ were subsequently determined.

The heat capacity of the surface soil (Caledon sandy loam) was calculated from equation (5). Mean values of $\chi_m = 0.459$ and $\chi_o = 0.024$ were determined by "loss on ignition" treatments of five soil samples, thereby reducing equation (5) to

$$C = 0.225 + \chi_w. \tag{6}$$

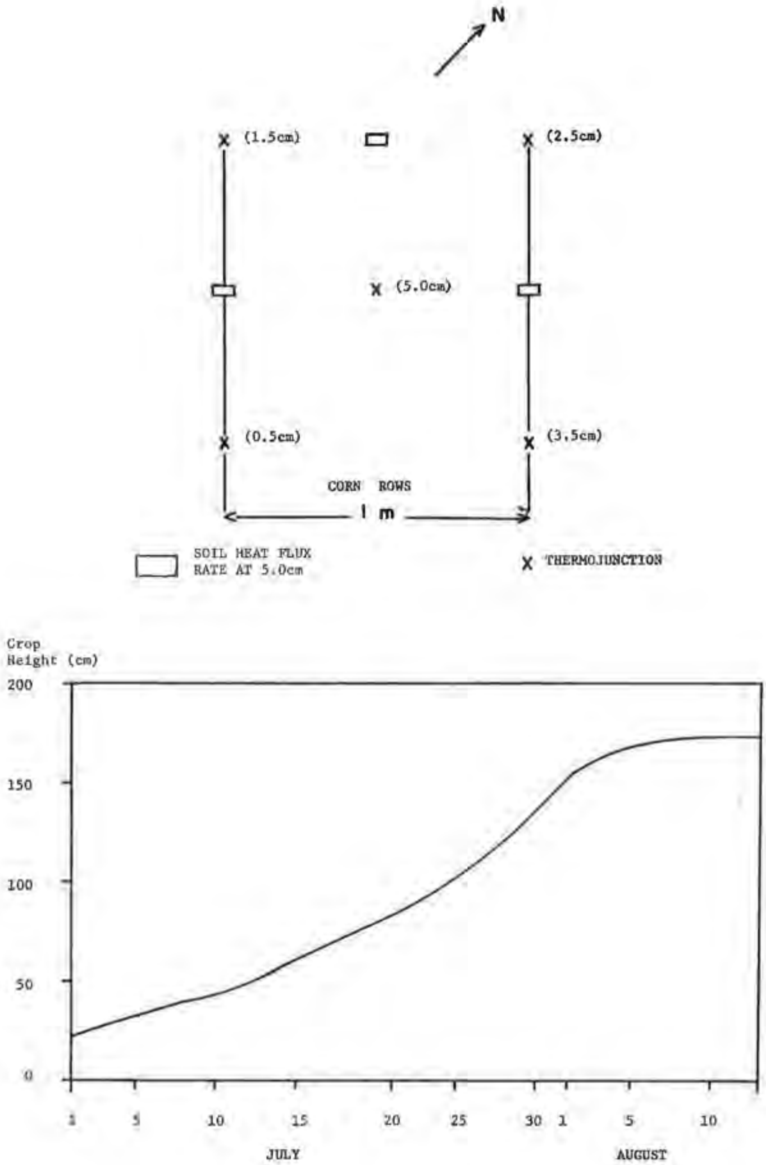

Fig.1 Energy Balance Investigations at Simcoe:
(a) upper - plan of field site and instruments;
(b) lower - growth curve of corn crop during July and August.

Volumetric soil moisture content was determined by gravimetric analysis of ten soil samples each day. The moisture content of each sample was calculated as

$$\chi_W = \frac{W}{D} \times \rho_s \tag{7}$$

where W is the weight of water in the sample, D is the dry weight of the sample, and ρ_s is the mean dry density of the soil. A total of 300 density samples produced a mean value of $\rho_s = 1.25$ g cm^{-3}. The average value of χ_W from the ten samples was then used to calculate C from equation (6), which in turn was used to calculate hourly values of soil heat flux divergence and G_o from equation (3).

3. Results

Soil heat flux divergence was found to contribute significantly to G_o on both an hourly and a daily basis. Hourly values of Rn, G_5, and G_o for two sunny days,(July 6 and August 11), are plotted in Fig. 2a. On both days G_o was considerably larger than G_5 in the morning hours, with a reversal of this situation occurring in the afternoon. The reversal ($G_5 > G_o$) continued throughout the afternoon of August 11 but was interrupted in the late afternoon of July 6. Hourly patterns such as these occurred persistently throughout the study period and can be related to the variations of soil heating and cooling. Surface soil temperatures increased rapidly in the morning hours due to solar heating, thereby producing large positive values of soil heat flux divergence. In the early afternoon hours the soil surface cooled and the divergence became negative. The interruption of this situation on July 6 was a characteristic of sunny days during the first two weeks in July. The corn plants did not provide a complete ground cover at that time, so the soil intercepted direct solar radiation in the late afternoon when the sun shone down the rows. A short period of soil heating resulted, causing a condition of positive divergence. After the middle of July the leaves shaded the soil throughout the day and the divergence tended to remain negative during the afternoon hours.

The effect of the developing crop is also apparent in the trends of daily values of the ratios G_o/Rn and G_5/Rn (Fig. 2b). There was an overall tendency for values of both ratios to decrease as the crop grew higher, with sharp daily variations occurring in periods of rains. For the entire study period, average values of the ratios were G_o/Rn = 0.083 and G_5/Rn = 0.049. Thus, even on an average daily basis, neglect of the flux divergence would have

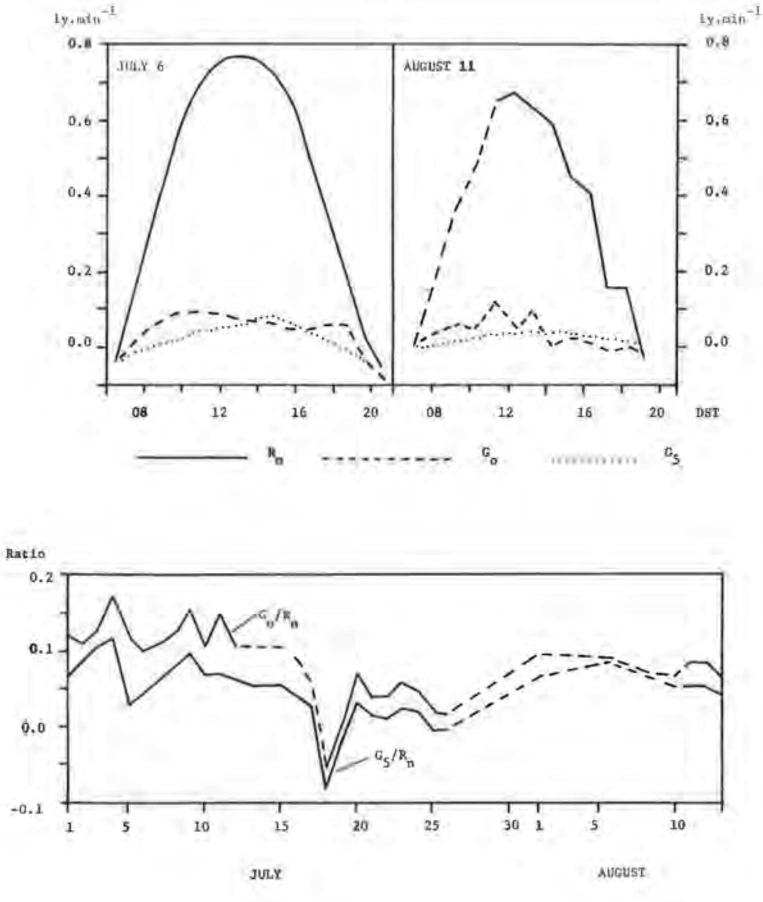

Fig.2 Net Radiation and Soil Heat Flux at Simcoe:
(a) upper - hourly values on two days;
(b) lower - heat flux/net radiation ratios, July and August.

produced a mean error of nearly 60% in the soil heat flux measurements. This error would have been larger at the beginning of the study period and smaller at the end because the magnitude of the divergence decreased over that period. It was particularly important to measure the divergence during individual hourly periods, as was apparent in Fig. 2a. As an example, the computed evapotranspiration between 0900 h and 1000 h on July 6 would have been overestimated by 27 percent if the divergence had been neglected. Although this figure was smaller for the comparable period on August 11 , it is clear that the divergence was still significant even when the crop was fully developed.

TABLE ONE

Regression Analysis for Daily Totals of G_o
(energy values in cal $cm^{-2}day^{-1}$, crop height in ^{o}cm)

Regression Equation	Correlation Coefficient	Standard Error
A. $G_o = 8.0 + 1.19\ G_5$	0.88	7.0
B. $G_o = -10.5 + 1.00G_5 + 0.07Rn$	0.91	6.3
C. $G_o = -4.5 + 0.95G_5 + 0.07Rn - 0.07h$	0.94	5.1

A linear regression analysis (Table One) indicates that daily values of G_o may be estimated with reasonable accuracy from Rn, G_5, and crop height h. When all three variables are used together the standard error is only 5.1 cal $cm^{-2}day^{-1}$. The error was not significantly improved when soil moisture content was included in the regression.

4. Conclusions

Soil heat flux divergence between the 5 cm depth and the soil surface involved significant quantities of energy for both hourly and daily periods. Consequently, there would have been large errors in the evapotranspiration estimates if the divergence had not been taken into account, even when the crop was fully developed.

A change in the instrumental array would be recommended for future studies. Rapid soil temperature fluctuations were occasionally observed during individual hourly periods at the beginning of July. These were probably caused by the presence of sunflecks near one or more of the thermocouple junctions. This problem might be eliminated by placing two or three junctions at each depth, so that the measured temperature change would then be more representative of the average situation. The measurement technique used in this study and the recommended improvement are slightly troublesome. However our experience indicates that considerably more attention should be given to soil heat flux measurements than has generally been the case in the past.

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NOTES SUR UNE METHODE DESCRIPTIVE DES TYPES DE TEMPS(1)

par

André Hufty*

LA METHODE EMPLOYEE

Il existe de nombreuses méthodes d'analyse des éléments du climat. Elles diffèrent entre elles par la façon dont les éléments sont groupés et par les périodes choisies.

J'ai comparé 8 stations climatiques pendant 6 ans à partir des fréquences journalières de combinaisons d'éléments du temps, ou fréquences de types de temps. Les éléments qui entrent dans ces regroupements sont les suivants: températures maximales et minimales et indices d'aggravation du temps ("bad weather index") basés sur la durée d'ensoleillement et les précipitations. Chaque jour est ainsi gratifié de deux symboles: le premier, de A à I est fonction de la température, le second dépend de l'état du temps (voir légende, p. 21).

Comme on a neuf classes de température et cinq classes d'aggravation du temps, on obtient 45 possibilités pour chaque jour. Ce nombre de types de temps est trop élevé et il a été réduit, compte tenu des résultats obtenus, à 15, chiffre plus maniable (voir légende, p.21).

QUELQUES RESULTATS OBTENUS

Pour simplifier les analyses, je vais comparer d'abord les seuls groupements thermiques, ensuite les seuls indices d'aggravation du temps et enfin les résultats complets mais seulement pour quelques stations afin de donner un aperçu de la methode utilisée.

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(1) Le manuscrit complet est déposé à la revue "The Canadian geographer".

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TABLEAU UN

Comparaison saisonnière des types thermiques en %

		Montréal				Normandin			
		H	P	E	A	H	P	E	A
Types de temps	H-I		21	78	6		5	52	2
	F-G	10	70	22	62	1	28	43	28
	E	28	9		26	13	62	5	45
	C-D	56			6	35	4		22
	A-B	7				50	1		2

Saisons: H (décembre à mars), P(avril, mai), E(juin à septembre), A(octobre, novembre)

TABLEAU DEUX

Indices d'aggravation du temps

(chiffres en nombre de cas observés en 6 ans)

Indices 2 et 3	J	F	M	A	M	J	Jt	A	S	O	N	D	Année
Québec	57	51	81	105	97	92	92	71	86	88	36	51	907
Caplan	59	92	101	105	93	98	108	89	97	77	68	73	1070

Indices 5 et 6	J	F	M	A	M	J	Jt	A	S	O	N	D	Année
Québec	102	84	68	52	61	58	67	83	67	79	116	110	947
Caplan	85	41	51	42	63	59	52	75	59	72	76	74	749

(1) Groupements thermiques

L'analyse du Tableau Un, va nous permettre de comparer deux stations fort différentes.

D'après ce tableau, qui regroupe les deux stations les plus contrastées, on constate qu'il y a un décalage d'une catégorie d'une ville à l'autre: en hiver, les temps froids sont nombreux à Montréal mais la température dépasse le point de gel plus du tiers des journées et ne s'abaisse que très rarement en dessous de $-30^{o}C$ ($-23^{o}F$); à Normandin par contre, les temps très froids sont la règle, avec deux dizièmes des nuits inférieures à $-30^{o}C$.

Les gelées nocturnes disparaissent au centre de Montréal au cours du mois d'avril mais persistent deux jours sur trois dans le centre de la province. En été, il peut faire très chaud partout, mais ces fortes chaleurs sont les plus fréquentes le long de la plaine du Saint-Laurent.

Le mois d'octobre est encore beau à Montréal mais il gèle déjà plus d'un jour sur deux à Normandin (contre un sur dix à Montréal). L'arrivée de l'hiver dans les deux villes est décalée de presque 6 semaines.

(2) Groupements par indices d'aggravation du temps (voir Tableau Deux)

Dans l'ensemble du Québec, la fréquence des temps clairs et secs passe par un maximum de mars à mai, descend lentement jusqu'au mois d'août, pour remonter temporairement en septembre, avant la chute qui conduit au minimum de novembre, suivie elle-même d'une remontée assez rapide jusqu'en mars.

En hiver, Québec est moins ensoleillé que Caplan; les deux stations se ressemblent à la fin du printemps. Au cours de l'été les temps clairs et ensoleillés sont nombreux partout mais surtout à Caplan, même en août. La chute de novembre est moins forte à Caplan qu'à Québec.

(3) Groupements complets (voir Fig. 1)

Amos a un régime de types de temps plus continental et plus nordique que Caplan. Le coeur de l'hiver est très froid (temps no 1) à Amos mais plus doux à Caplan (temps no 3) où les dégels ne sont pas rares. Le printemps est tardif dans les deux stations, à cause de la latitude (Amos) ou de la proximité de l'océan (Caplan). Dans le nord-ouest les contrastes journaliers sont très grands car les premiers jours chauds coincident avec les derniers gels sévères (en avril, temps 3 et temps 17). En juin, juillet les temps beaux et chauds

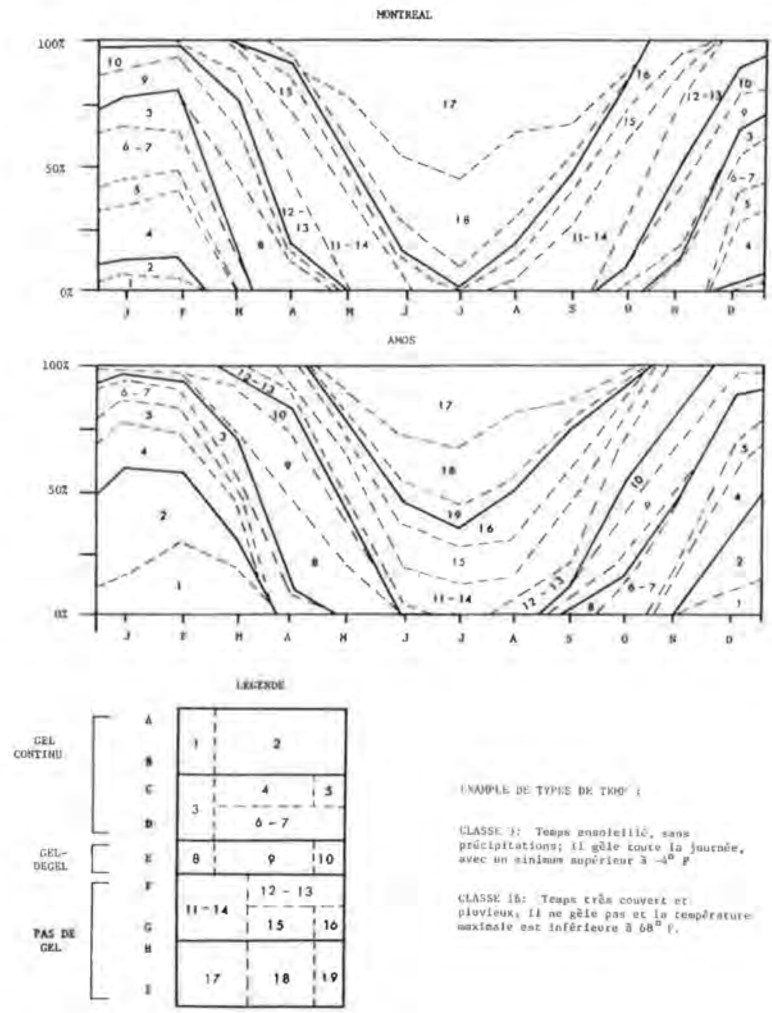

Fig. 1 Types de Temp: Montréal et Amos.

LEGENDE DES TYPES DE TEMPS

Catégories de température (^{o}F):

			minimum journalier	maximum journalier
	A	polaire ou glacial	-41 -23 à -40 (-40°C)	31 31
gel continu	B	très froid	-5 à -22 (-30°C)	31
	C	froid	13 à -4 (-20°C)	31
	D	frais	31 à 14 (-10°C)	31
passage gel-dégel	E	frisquet	32 et maximum	32
	F	tempéré	33	de 33 à 50 (10°C)
	G	doux	33	51 à 68 (20°C)
pas de gel	H	chaud	33	69 à 86 (30°C)
	I	très chaud ou torride	33 33	87 à 95 (35°C) 96

Indices d'aggravation du temps: additionner les chiffres ci-dessus pour obtenir un indice journalier variant de 2 (temps ensoleillé et sec) à 6 (temps couvert avec précipitations). Les indices 3 à 5 indiquent un temps variable avec augmentation des nuages et des précipitations.

(I) catégories

1. nulles
2. traces ou 0.01 pouces d'eau tombée
3. 0.02 pouces ou plus

(II) catégories d'ensoleillement, basées sur les rapports d'ensoleillement:

1. plus de 6/10 de l'ensoleillement possible
2. de 2 à 6/10 de l'ensoleillement possible
3. moins de 2/10 de l'ensoleillement possible

Remarque: Utiliser les valeurs suivantes, des rapports d'ensoleillement en heures et dizièmes d'heure extraites de l'annuaire du Québec.

	J	F	M	A	M	J	Jt	A	S	O	N	D
6/10	5.3	6.0	7.1	8.1	9.1	9.5	9.2	8.7	7.7	6.6	5.7	5.1
2/10:	1.7	2.0	2.4	2.7	3.0	3.1	3.0	2.8	2.6	2.2	1.9	.17

sont plus fréquents à Amos et les jours ensoleillés restent souvent frais à Caplan (temps 11-14). Cependant, dans le nord-ouest, on observe plus un grand nombre de jours à ciel couvert et pluvieux (temps 15, 16, 18, 19). En août et en septembre, les temps clairs se refroidissent mais il gèle rarement près de la mer et la fin de l'été y est très ensoleillé. Dans le nord-ouest, les temps doux et très couverts sont très nombreux (temps 15-16) et les contrastes journaliers sont violents en septembre qui est déjà un mois d'automne. De septembre à octobre la diversité des types de temps augmente. Le froid s'accentue et la nébulosité devient plus grande: ces deux effets vont s'amplifier en novembre où le type de temps le plus caractéristique est le numéro 10, c'est-à-dire un jour sombre avec pluies diurnes et neiges nocturnes. Les gelées nocturnes passent de 0 à 100% du début septembre à la fin novembre à Amos mais à Caplan, même en octobre les temps clairs ont peu de gelées et des faibles amplitudes de température (temps no 11 ou 14).

Pour donner une idée meilleure de la méthode, il faudrait comparer plus de stations, avec des chiffres précis pour les différentes catégories. Cependant cette analyse sommaire permet de faire ressortir la continentalité d'Amos (plus de temps clairs et froids en hiver, plus de temps chauds en été), et l'effet de sa position en latitude (températures plus basses, été plus perturbé à cause des dépressions cycloniques décalées vers le nord à cette saison). L'influence maritime se fait sentir à Caplan par une atténuation des contrastes entre l'hiver et l'été et par un décalage des saisons intermédiaires (printemps tardif, automne très doux).

CONCLUSION

Cette méthode est simple à employer (70 étudiants de licence en géographie ont aidé au dépouillement des données journalières), assez laborieuse mais on peut faire calculer les fréquences par un ordinateur. La méthode permet une bonne description des climats à partir des situations journalières qui sont plus significatives que les moyennes dans les pays tempérés où l'irrégularité du temps est très forte. Elle peut être améliorée facilement en définissant autrement les classes: c'est ainsi qu'en hiver on pourrait tenir compte du vent, classer les jours par indices de refroidissement (wind chill), mettre à part les jours de tempêtes de neige. De même en été, il faudrait tenir compte de l'humidité relative et du bilan d'eau. En somme, cette méthode est ouverte à quantité d'ajustements qui pourraient donner des résultats intéressants en climatologie appliquée. La discussion le fera grandir.

RESEARCH REPORT

Since the publication of the last issue of the Bulletin daily totals of solar and net radiation for Mont St. Hilaire have been compiled for the period 1966-69. Preliminary analysis of these totals has been concerned with three topics: (1) comparative measurements of solar radiation with three different instruments; (2) variability of surface albedo during the year; and (3) linear relationships between solar and net radiation.

Analysis for part (1) indicates that both the Belfort bimetallic actinograph and the Yellot Mark IV Integrating Sol-A-Meter have a non-linear response at low radiation values. However, when they have been calibrated against a control instrument (in this case a Kipp and Zonen solarimeter) their accuracy seems reasonable for many purposes. In this case the standard errors of prediction were found to be about 10 percent for daily values and 5 percent for weekly totals.

The average albedo of the short grass cover during the summer of 1968 was 0.25 with a standard deviation of 0.03. A greater variability was found for snow which, for the winter months of 1968, had a mean of 0.85 and a standard deviation of 0.14.

Linear relationships between solar and net radiation have been determined for daily and weekly totals for both grass and snow. Correlation coefficients average about 0.90 and standard errors of prediction are approximately 30-40 langleys per day. These results clearly indicate the feasibility of using this technique for daily or weekly periods, rather than monthly periods as has been common in the literature.

Within the field of urban climatology, a pilot study has been started to examine certain aspects of the climate of Montreal in relation to human physiological stresses. The study aims to sample conditions within the urban area by taking observations at different places during the different seasons of the year, and applying the results to an examination of physiological stresses through the use of standard formulae.

With this end in view, twelve sites were selected to represent the city area. They were chosen along an east-west axis from the St. Lawrence river to van Horne street on the other side of Mt. Royal. Thus, the sample embraces the tourist area of Old Montreal, the city's business district in the vicinity of St. James Street, the commercial core of the downtown area, and some of the residential areas well within the urban region. The actual positions chosen also sample different kinds of urban structure and, for the most part, are concerned with places where large numbers of people are found in the streets. Since the study aims to relate the city climate to people in the street, the choice of such sites was deemed important as was the choice of the time of observation: 1200-1400 hours, which covers the lunch-hour for most people in the downtown area. This time also is a period of the day when conditions of temperature, humidity, and radiation tend to change least, so that it was possible to obtain some impression of variation from place to place within the city.

Observations of wind speed and humidity were made by means of a car traverse along the traverse route. Sensitive cup anemometer (C.F. Casella & Co.) were used for the former, and an Assmann ventilated hygrometer for the latter. Both were mounted on a car in positions which calibration showed too be minimally influenced by the effects of the vehicle itself. The police Department of the city co-operated by granting a special permit for the vehicle to be parked whenever and wherever necessary for the observations. By selecting "no parking areas" for the actual site of observations it was possible to ensure that each observation spot was identical for every traverse. Observations began at the end of July, 1970, and continued at selected intervals through February, 1971. The selection of observation periods was made as far as possible to sample the weather of different seasons. Each observation period lasted 7-10 days to cover a full weather cycle, and the observations were made each day during the period in question.

The reslting data were incorporated in appropriate formulae such as the comfort index or the wind chill factor. It had been impractical to take radiation observations during the traverses. However, at every observation a note was made as to whether the observation was being made in shade or in sunshine. Sky-line measurements of each site were also used to prepare sky-line profiles around each site. These enabled an evaluation of radiation for each site to be made by obtaining the hourly data of global and sky-diffuse radiation observed at Jean Brebeuf College for the Federal Meteorological Service, and adjusting the figures for the sky-line conditions at each observation site. Thus it has proved practical to include in the analysis formulae which incorporate the radiative heat load on the human body.

Analyses of all these data are currently being undertaken and will be the subject of later reports in this <u>Bulletin</u> and elsewhere.

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NEWS AND COMMENTS

Messrs G. D. Mackay & B. F. Findlay of the Department of Transport (Meteorological Branch) visited McGill University in October and participated in a graduate seminar devoted to discussing two aspects of urban climatology: a pilot study of human comfort values in the city of Montreal, and a project to evaluate the differences in the radiation balance between Montreal and the adjacent countryside.

The second annual reunion of Friends of Climatology was held March 12-13. The hosts for the occasion were members of the Department of Geography at MacMaster University. Social activities and a period of discussion which covered many practical problems of climatological research in Canada, were followed by short talks by Professors F.K. Hare and H. Lettau, and a keynote address on East African Rainfall by Professor Thompson of Brock University.

Professor B. J. Garnier was an invited lecturer to the WMO Seminar on Agricultural Meteorology held in Barbados in November, 1970. His topic of discussion was the organisation of Observation Networks in Agrometeorology.

There have been some recent modifications in the climatological courses being offered in the Department of Geography at McGill University. In the past there have been two full undergraduate courses at 3rd and 4th year levels respectively. These have now been divided into four half-courses, each lasting one semester. The four half- courses now available are: (a) Climatic Environments; (b) Ecological & Physiological Climatology; (c) Urban Climatic Environments; and (d) Agro & Hydro-climatology. The purpose of this change is to widen the effective offering for students requiring some climatology especially applied climatology, but who do not intend to specialize in the field. Slight changes in prerequisites will make it possible for those who obtain basic climatology outside of geography, e.g. through meteorology, to enter the courses without going through the courses which comprise the standard prerequisites.

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