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CONTENTS

No. 29 April, 1981

Simulating the Effect of Urbanization on the Human Long Wave Radiation Environment
by Stanton E. Tuller....................page 1

Prediction du Gel dans le Sol
par Bhawan Singh....................page 13

Climatology at the 24th International Geographical Congress
by Stanton E. Tuller....................page 33

News and Comments....................page 37

SIMULATING THE EFFECT OF URBANIZATION ON THE HUMAN LONG WAVE RADIATION ENVIRONMENT

by

Stanton E. Tuller*

Climatology, as practised by geographers, has always placed primary emphasis on the practical and applied aspects of the mutual interaction between people and the atmosphere. Although geographers have made notable advances in the simple compilation of climatic data, climatic description and the understanding of the physical processes which control climate, there has always been a concern for the practical significance of the results in terms of a better comprehension of how the atmosphere affects people and their activities and vice versa.

Today, the applied aspects of climatology are gaining increased appreciation from the public at large. As the world becomes more densely populated, and its resources become more heavily utilized and limited, its people have become more aware of the need to maximize the efficiency of their interaction with the finite environment. This has created an awareness of how people's modification of the earth's surface can cause changes in the climate and a concern for how these climatic changes can then affect people, and their activities.

Perhaps the major way in which people today are modifying the local climate which in turn affects them is by the building of cities (Landsberg, 1970). The changes in surface materials and vertical structure, the modification of the composition of the atmosphere, and the direct emission of heat combine to affect and alter all climatic elements. As the world becomes more and more urbanized, cities become bigger and their effect on local climate becomes more pronounced. This urban induced climatic modification, in turn, affects a greater proportion of the world's population.

The study of urban climatology has been going on for quite some time. The trend in recent years, like that in other branches of climatology,

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has been toward more emphasis on the elements of the radiation and energy budgets. A major stimulating factor in this trend is the realization that a complete understanding of the causal processes which produce the urban climate must be based on the radiation and energy budgets. A second factor is the appreciation that the compenents of the radiation and energy budgets are important climatic elements in their own right and are responsible for a number of the practical effects the urban alteration of the atmosphere has on the human population.

The purpose of the present paper is to present some data concerning the urban effect on one component of the radiation budget: long wave radiation. The paper also investigates what direct effects this modification might have on people themselves through the processes of human thermal exchange.

Methodology

The observational data reported on in this paper were taken in a residential area of Victoria, B.C. during seven clear nights in April, 1980. All observations were taken beginning between 3.5 and 4.0 hours after sunset.

The amount of long wave radiation emanating from basic components of the environment was measured with a Stoll-Hardy HL-4 infrared radiometer. The long wave radiation measured by this instrument includes both that emitted and reflected by an object and no attempt is made here to separate the two components. The features observed were grass and pavement on the ground surface, and buildings and open sky in the upper hemisphere.

Wet and dry bulb air temperatures were measured with a sling psychrometer and used to determine the atmospheric vapour pressure. Wind speed was measured at a height of 1.3 m with a hot wire anemometer.

The effect of thé climatic environment on human thermal exchange can be determined by solving the human body heat budget equation. This equation, at night in the absence of solar radiation, can be written as:

$$S = M - E \pm L^* \pm K - E_r \pm C_r \ \mathrm{W\ m^{-2}} \qquad (1)$$

where: S = net storage of body heat,
M = metabolic heat production,
E = evaporative heat flux density from the skin surface,
L^*= net long wave radiation exchange,
C = convective heat flux density from the skin surface,
K = conductive heat flux density,
E_r= evaporative heat flux density from the respiratory tract, and
C_r= convective heat flux density from the respiratory tract.

A positive sign indicates a net gain of heat by the body for all terms in equation (1).

Equation (1) was solved for a standing person ($M = 91\ \mathrm{W\ m^{-2}}$) with a skin temperature of 33°C (about what would be expected for a comfortable person at this activity level).

Convective heat flux density from the skin surface (C) was computed using the formula:

$$C = h_c\ (T_o - T_a)\quad W\ m^{-2} \qquad (2)$$

where: h_c = convective heat transfer coefficient (W m^{-2} $^oC^{-1}$),
T_o = weighted average clothing - exposed skin surface temperature (°C), and
T_a = air temperature (°C).

The factor h_c was taken as a square root function of the wind speed measured at the 1.3 m level. The temperature of the outer clothing surface needed to compute T_o was taken to be the temperature which produced a skin-outer clothing surface temperature gradient sufficient to dissipate the heat supplied by metabolic heat production minus that lost via total evaporative heat flux density and convective heat flux density from the respiratory tract ($M - E - E_r - C_r$).

Evaporative heat flux density from the skin surface (E) was determined using the method proposed by Gagge, Stolwijk and Nishi (1971). A standing person in a cool environment, such as that investigated in the present study, would not be actively sweating and the formulae of Gagge, Stolwijk and Nishi (1971) reduce to:

$$E = .06\ \frac{Lh_c\ (37.73 - e_a)}{(1.0 + 0.143\ h_c\ I_c)}\quad W\ m^{-2} \qquad (3)$$

where: L = the Lewis relation (2.2°C mm Hg $^{-1}$),
e_a = atmospheric vapour pressure (mm Hg),
I_c = mean clothing insulation over the body surface (clo), and
37.73 = the saturation vapour pressure at the skin temperature of 33°C.

Evaporative (E_r) and convective (C_r) heat flux density from the respiratory tract were computed using Fanger's (1972) equations which, in the units used in the present study, are:

$$E_r = 0.0023\ M\ (44.0 - e_a)\quad Wm^{-2} \qquad (4)$$

$$C_r = 0.0014\ M\ (T_x - T_a)\quad Wm^{-2} \qquad (5)$$

$$T_x = 32.6 + 0.066\ T_a + 32.0\ w\ ^\circ C \qquad (6)$$

where: T_x = temperature of expired air (°C),
w = mixing ratio of the air (gm Kgm $^{-1}$), and
44.0 = the saturation vapour pressure at the internal body temperature (mm Hg).

Heat exchange between the human body and the ground surface via conduction (K) is usually very small for a standing person unless he or she has awfully big feet and poorly insulated shoe soles. It is neglected in this study.

The net long wave radiation exchange between the human body and the surrounding environment (L*) is the component of the body heat budget equation of interest in the present study:

$$L^* = L\downarrow - L\uparrow\quad Wm^{-2} \qquad (7)$$

Where: $L \downarrow$ = long wave radiation from the surrounding environment absorbed on the outer body surface, and
$L \uparrow$ = long wave radiation emitted by the outer body surface.

$L \uparrow$ was determined from:

$$L \uparrow = \varepsilon_h \sigma A T_o^4 \quad W m^{-2} \tag{8}$$

where: σ = Stefan - Boltzmann constant,
ε_h = emissivity of the outer body surface (taken as 0.97), and
A = the proportion of total body area which emits radiation to the surrounding environment,
and T_o is in °K.

A is a function of the proportion of the total body area which emits radiation to the environment rather than to other parts of the body and the increase in total radiating area created by clothing. Both of these factors were accounted for using the data presented by Fanger (1972).

Long wave radiation from the surrounding environment absorbed by the outer body surface ($L \downarrow$) was determined by applying the appropriate view factors to the amount of long wave radiation coming from the four components of the radiating environment considered in this simulation (open sky, buildings, pavement and surface vegetation). It was assumed that the human body would absorb 97 percent of the incident long wave radiation.

The values of all the input variables for the components of the body heat budget equation were either measured or assumed with the exception of clothing insulation which is needed to determine L*, C and E. The interval halving method was used to determine the amount of clothing insulation (I_c) required to balance the body heat budget equation within 0.1 W m^{-2} with no net change in body heat storage (S = 0). This value, hereafter called the equilibrium clothing insulation or clothing requirement, can be thought of as the amount of clothing, averaged over the whole body surface, needed to keep a person with a specified activity level in a comfortable state of thermal neutrality in a given climatic situation. It should be viewed as a useful index which allows the human effects of different climatic environments to be compared on the basis of a single number. Its primary purpose is for climatic comparison. It should not be thought of as the actual amount of clothing any particular individual will desire or require since human sensations and physiology vary somewhat from person to person. It is felt, however, that comparing climates in terms of equilibrium clothing insulation is a simple method which allows people to easily visualize and compare the human effects of different climatic situations.

The unit of clothing insulation used here is the clo. One clo is the amount of insulation which allows the passage of 1.0 W m^{-2} with a temperature gradient of 0.155°C. One clo is considered to be the amount of insulation needed to keep a resting person comfortable with an air temperature of 21 °C, air flow of 0.1 m sec^{-1}, and a relative humidity of less than 50%. Good clothing provides about 4.0 clo per inch and a typical business suit with associated undergarments is usually described as providing about 1.0 clo of insulation.

The model of human thermal exchange described above was used to simulate the effects that changing the nature of the surrounding environment through urbanization would have on human long wave radiation and equilibrium clothing requirement. The simple simulation described here considers two types of ground surface material (grass and pavement) and two components of the upper hemisphere (open sky and buildings). The mean values over the seven April observation nights of air temperature, wind speed, vapour pressure and the amount of long wave radiation coming from the four environmental components were used as input data for the basic model. The initial simulation considers a purely rural environment to be one in which the surface is all grass vegetation and there are no vertical obstructions blocking the open sky. This would represent an open pasture situation. Urbanization is simulated by introducing increasing proportions of pavement with its associated long wave radiation into the human ground surface view factor, and buildings with its long wave radiation into the human upper hemisphere view factor.

The various view factors utilized were determined using the nomograms of Fanger (1972) for a standing person whose location but not orientation with respect to the elements of the environment is known. In order to simplify computation it was assumed that a person is located midway between two buildings located at least 20 m apart. This provides a relatively constant ratio of the ground surface to upper hemisphere view factors. As a person moves closer to a vertical wall the upper hemisphere view factor makes up a progressively greater proportion of the total view factor and the presentation of simulation results become much more cumbersome.

The results of the computer model are graphed. This allows the simulated effect of changing the environment by paving the surface and erecting buildings on human long wave radiation and equilibrium clothing insulation to be easily determined for clear spring nights in Victoria.

Observed Long Wave Radiation

Components of the urban environment emit more long wave radiation than do the natural features of an open rural area. Pavement is warmer than grass or other surface vegetation on cool, clear nights and emits more long wave radiation. An average of 25 W m^{-2} more long wave radiation was observed coming from pavement surfaces than from grass surfaces on the clear April nights in Victoria.

Buildings have both a higher temperature and emissivity which allows them to emit more long wave radiation than the clear night sky. They probably also reflect slightly more long wave radiation although the difference is very small. The average building-open sky long wave radiation difference observed on clear April nights in Victoria was 88 W m^{-2}.

Simulation of the Human Effect of Urban Long Wave Radiation

Although the differences in the amount of long wave radiation emanating from the various components of the environment are quite large, the question arises - are these differences significant? Will increasing the amount of pavement and buildings have any practical effect?

It is to answer questions such as this that the use of simulation models is gaining increased importance in applied climatology. With the increased awareness of climate and its influences by the public, climatologists are being asked more and more to evaluate what practical effects proposed changes of the earth's surface will have on the local climate.

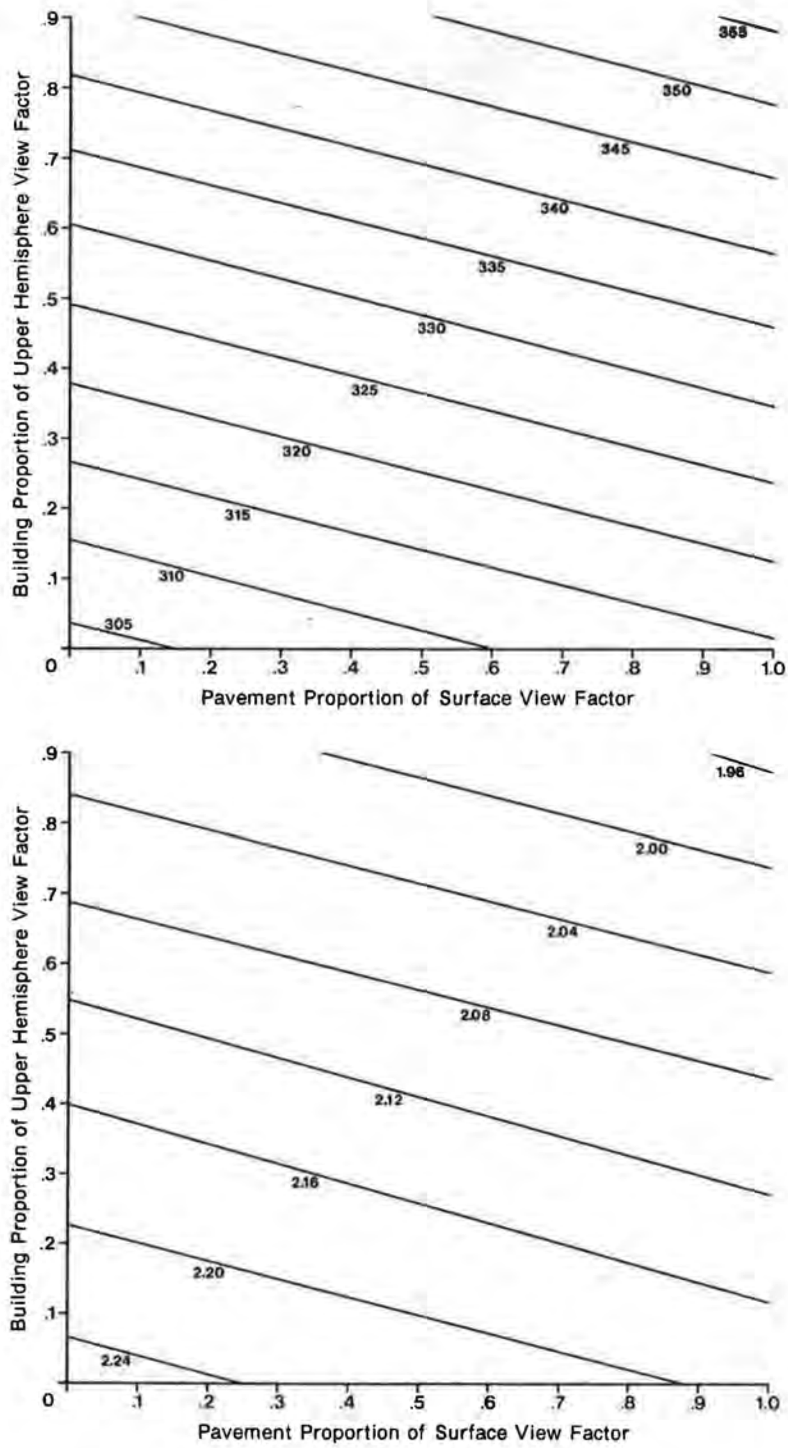

Fig. 1.. Environmental long wave radiation (W m^{-2}) (top) and equilibrium clothing requirement (clo) (bottom) with constant sky radiation.

In many cases the evaluation involves situations for which no adequate observational data are available. An analysis of the effects, therefore, is often based on the use of mathematical models which allow the climatic effects of proposed developments to be simulated and taken into consideration before the actual changes begin. Models vary greatly in sophistication and complexity from single equations which consider only one climatic element to complete energy budget models. Models are available to evaluate both the climatic change itself and, as is done in the present study, to assess some of the practical effects of the climatic change. Although most models are still in the early stages of development and require much more work before they can give an accurate appraisal of reality, they still provide a very useful method of assessing the effects of different development alternatives.

The question of whether or not changing the surface from vegetation to pavement and constructing buildings will have any practical effect on climate depends, of course, on what particular thing or activity we are concerned with as recipient of the effect. A climatic modification which is favourable for one thing may be unfavourable for another. The assessment of the practical consequences of any man induced climatic alteration must focus on specific things or activities.

One convenient and important object of interest is the human population itself. People will always be exposed to the climatic effects of urbanization through their own thermal exchange processes. The building of cities definitely modifies the local climate to which the people who inhabit the city are exposed. The number of potential urban morphologies is quite large, however, and by careful, studied choice we have the opportunity of selecting the one which will create the most favourable human environment. The use of climatic simulation models allows the planner and developer to evaluate the practical, human climatic effects of a number of possible urban development alternatives. This, in turn, will aid in the creation of the most efficient climatic environment for the human population which must ultimately occupy the area.

Simulations can vary greatly in their completeness and complexity and the results can be presented in a number of ways. A very elementary simulation investigating the urban effect on the human long wave radiation environment in a particular area might simply look at the effects of various combinations of pavement and building proportions of a standing person's surface and upper hemisphere view factors.

The seven April observation periods in Victoria had an average air temperature of 9 °C, a vapour pressure of 5.9 mm Hg, and a wind speed of 0.5 m sec^{-1} at the 1.3 m level. According to the human thermal exchange model used in this study (the points of origin in Fig. 1) a standing person would receive about 305 W m^{-2} environmental long wave radiation under these conditions in an open environment with a grass surface. This is equivalent to a large, flat pasture in a rural area. The equilibrium clothing requirement would be 2.26 clo.

Altering the ground surface so that one-half of the person's surface view factor is pavement would increase the environmental long wave radiation to about 309 W m^{-2} and decrease the equilibrium clothing requirement to 2.22 clo. Completely paving the surface would change the values to 315 W m^{-2} and 2.19 clo.

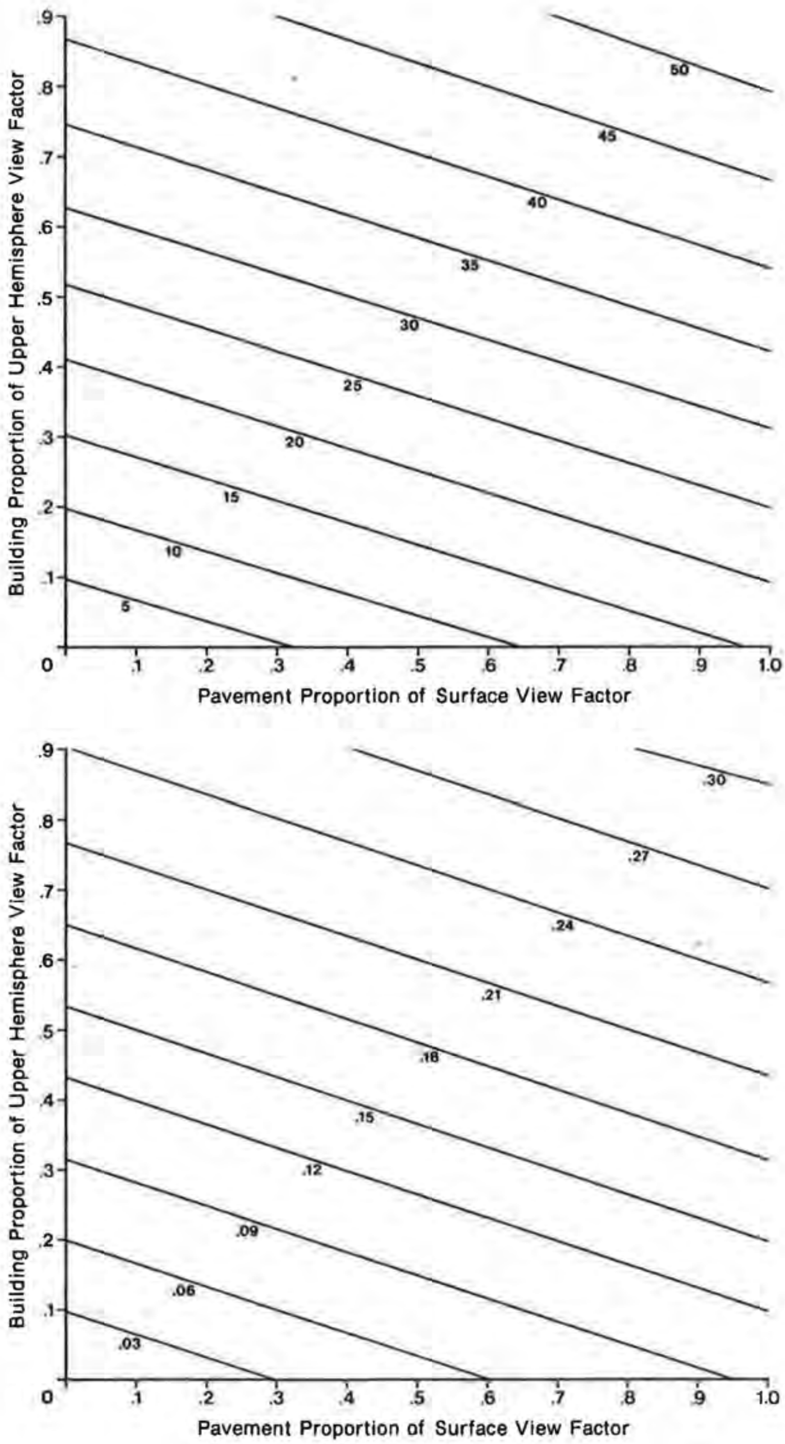

Fig. 2. Difference in environmental long wave radiation (W m^{-2}) (top) and equilibrium clothing requirement (clo) (bottom) from those in an open rural environment, with variable sky radiation.

The replacement of the cold, clear night sky by buildings will also affect the human radiation environment and clothing requirement. An urban street canyon where one-half of the standing person's upper hemisphere view factor is building would increase the environmental long wave radiation to about 325 W m^{-2} and reduce the equilibrium clothing requirement to 2.13 clo. This situation is equivalent to a person standing midway between two 7.5 m buildings located about 20 m apart. It should be noted here that for a particular building arrangement the buildings make up a larger proportion of a standing person's upper hemisphere view factor than they do for the total view factor of a spot on the horizontal ground surface. It is obvious that human long wave radiation is affected more by the urban modifications to the upper hemisphere environment than to the ground surface. This is because the building-open sky long wave radiation difference is much greater than the pavement-grass difference (3.5 times greater in the Victoria spring observations). The upper hemisphere also represents a greater proportion of the total view factor for a standing person than does the ground surface.

Nomograms, such as those in Fig. 1, allow the effects of different pavement-vegetation surface and/or building-open sky combinations to be quickly determined. For example, at a location mid-way between two 20 m tall buildings located 20 m apart, the buildings would represent about 80 percent of a standing person's upper hemisphere view factor. This situation would provide about 351 W m^{-2} environmental long wave radiation and require 1.98 clo equilibrium clothing insulation if the surface were completely paved.

If the buildings were only one-half as tall (building proportion of upper hemisphere view factor is about .60), the environmental long wave radiation would be reduced to 341 W m^{-2} and equilibrium clothing requirement increased to 2.04 clo. Making the street twice as wide (building proportion of upper hemisphere view factor is .35) would provide 330 W m^{-2} environmental long wave radiation and require 2.10 clo. Reducing the building height by one-half and leaving one-half of the ground surface in vegetation would produce a climatic environment where environmental long wave radiation would be 335 W m^{-2} and the equilibrium clothing requirement 2.07 clo.

The absolute values of equilibrium clothing insulation presented in Figure 1 are obviously controlled by the values of other climatic factors as well as the differences in long wave radiation expected from the various components of the environment. The absolute values obtained from any mathematical model are also dependent on the assumptions and methods employed in the model itself. Simulations are most usefully employed, therefore, to determine the differences expected between various development alternatives rather than expected, absolute values. Nomograms which show differences from some initial situation are, therefore, simpler and easier to use; they also focus attention more readily on the major aspect of interest than those which report absolute values.

Simulations can include a number of expected environmental alterations. The paving of the surface and the replacement of the open sky by buildings are not the only effects of urbanization on the human long wave radiation environment. An urban area also experiences higher nocturnal air temperatures than the pre-existing rural area. The warmer atmosphere will, in turn, emit more long wave radiation. The effects of the urban heat island, therefore, should be considered when modelling the urban long wave radiation environment.

The magnitude of the urban heat island will increase as the proportions of surface pavement and vertical buildings increase, although our observational data base is still too sparse to develop an accurate expression which will predict the precise effects of different surface type-upper hemisphere view factor combinations. In the absence of such an expression the urban heat island effect was approximated in the present study by increasing the atmospheric long wave radiation as a simple function of the pavement and building proportions of the surface and upper hemisphere view factors. The increase ranged from zero, with no pavement and no buildings, to 21 W m^{-2} (equivalent to a 5 °K increase in radiant sky temperature) at a pavement proportion of the surface view factor of 1.0 and a building proportion of the upper hemisphere view factor of 0.80. The building proportion was given twice the weight of the pavement view factor. This increase in atmospheric long wave radiation would correspond to a 5.55 °C increase in air temperature if the emissivity of the atmosphere were .90.

Although this procedure is admittedly a crude and probably quite conservative approximation of reality, it does illustrate the type of approach which can be taken in simulating the practical effects of urban climatic modification. More valid expressions may be utilized when they become available. Other urban effects on atmospheric long wave radiation, such as changes in emissivity, are omitted here because of lack of sufficient information; their influence could, if necessary, be treated in a similar manner in future more comprehensive models.

The total effect of a warmer sky on the human long wave radiation environment is also dependent on the open sky view factor. The nature of the urban environment however mitigates against such warning having a large human effect. The warmest parts of the city at night are usually those with the tallest buildings and lowest open sky view factors. These counteracting factors reduce the overall influence of the warmer atmosphere on the total environmental long wave radiation received by the human body. The human effect of the higher radiant sky temperature, therefore, is most marked for areas with a completely paved surface and a moderate open sky view factor according to the assumptions used here.

The results of the simulations, including the effect of increased atmospheric long wave radiation, are presented as differences from the open, grass surface, rural environment in Fig. 2. Repeating the example given earlier, a person standing mid-way between two 20 m tall buildings located 20 m apart would receive 50 W m^{-2} more environmental long wave radiation and require .29 clo less equilibrium clothing insulation in a completely paved urban setting than he would in the rural environment. The human cost of reducing the building height to 10 m would be about - 8 W m^{-2} environmental long wave radiation (+42 rather than +50 W m^{-2}) and +.05 clo (-.24 rather than -.29 clo). Keeping the building height 10 m and spacing them twice as far apart would provide 32 W m^{-2} more human environmental long wave radiation than the open rural environment but 18 W m^{-2} less than if the buildings were 20 m apart. The equilibrium clothing requirement would be .19 clo less than in the rural setting and .10 clo more than with the closer buildings. Paving only one-half of the surface would give an environmental long wave radiation increase of 43 W m^{-2} compared to the rural situation and reduce the equilibrium clothing requirement by .25 clo.

The above example illustrates how the results of simple simulation models can easily be used to compare and assess the human effect of different development alternatives. The results of very simple, one element simulations, such as that illustrated here, can be presented in terms of graphs, nomograms or tables which can be quickly consulted to determine the effect of any combination of pavement-vegetation and buildings-open sky view factors. The ready availability of microcomputers, however, also allows the effects of much more complex and comprehensive situations to be quickly and easily evaluated.

The question of the significance of the simulated changes in long wave radiation produced by urbanization remains to be answered. Does a change of .2 or .3 clo in the equilibrium clothing requirement make any difference to the person in the street? The answer depends on the individual person.

A .2 clo reduction in equilibrium clothing insulation represents about nine percent of the total needed by a standing person in the open, rural environment simulated in the present study. It is about one-fifth of the insulation provided by a typical business suit or about that of wool cloth 1.5 mm thick. It is also about one-half of the insulation value of light summer clothing.

Fourt and Harris (1949) report that in hot environments the human body can sense insulation changes as small as .01 clo. Thus, the effect of increasing the environmental long wave radiation will probably be sufficient in highly urbanized areas to have a noticeable effect on human thermal exchange and comfort. In cool climates, such as the one investigated here, the urban effect will be favourable and provide a more comfortable human thermal environment. In hot environments, however, the reverse is true. Even in the tropics the clear night sky represents an important radiation sink for the human body. Replacing this with warm buildings will not be beneficial for the comfort of a person on the street.

Summary and Conclusions

The long wave radiation budgets of urban areas can be quite different from those of rural areas. Part of this difference is created by the dissimilarity of ground surface types and the replacement of open sky by building surfaces in the urban area. Pavement surfaces were found to be the source of 25 W m^{-2} more long wave radiation than adjacent grass surfaces on cool, clear, spring nights in Victoria. 88 W m^{-2} more long wave radiation come from vertical building walls than from the clear, night sky.

Many aspects of urban climates are amenable to simple modelling and simulation procedures which allow the climatic effects of contemplated urban developments to be assessed. Proper use of simulation models can assist in the selection of the design which has the most favourable climatic effect among a number of viable alternatives.

Long wave radiation is one climatic element which can, and should, be considered in assessing the human climatic effects of urbanization. The effect of changing the surface type from vegetation to pavement and the replacement of open sky by buildings is sufficient to have an effect on the heat budgets and, therefore, the comfort of people on the street. The simulations undertaken in the present study have indicated that the urban effect is sufficient to be perceived by people. The result will be favourable for human comfort in cool or cold weather.

One important factor which must always be kept in mind is that there is no such thing as a single "urban climate". Instead, any city is a collection of countless individual microclimates. This can be demonstrated no better than by considering the long wave radiation regime. Whether it is the long wave radiation budget of a spot on the ground surface or the environmental long wave radiation incident on the human body, the magnitude is highly dependent on view factor geometry. The present study has demonstrated that even subtle changes in the upper hemisphere view factors of buildings and open sky or the nature of the ground surface will alter the long wave radiation climate. Since almost every point in a city has its own unique view factor situation it also has its own individual radiation microclimate.

In this lies a definite challenge. This study has shown how simple models may be used to help indicate the microclimate effects of future urban developments. The challenge to the applied climatologist is to aid in the development of better, more comprehensive simulation models which: a) address applications of practical concern, b) are simple and easy to use, yet c) are of sufficient accuracy and d) are representative enough, despite the problem of the limitless number of microclimates. It is important, too, that the models will appeal to those charged with planning the nature of future urban developments. The process will not be easy and will involve a great deal of both observational and theoretical work. The opportunity to help provide the tools which will aid in the more rational planning and consideration of future, man-induced changes in local climate, however, should not be missed.

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PREDICTION DU GEL DANS LE SOL, BAIE JAMES, QUEBEC

par

Bhawan Singh*

Introduction

D'après Brown (1967, 1979) et Ives (1962) la plupart du territoire de la Baie James se trouve dans la zone de pergélisol discontinu. Plus récemment, il y eut des rapports verbaux (communications personnelles avec des travailleurs) et écrits (Vincent 1974 et 1976) de l'existence d'îlots de pergélisol dans la région. De plus, pour une pareille région latitudinale, soit Schefferville, il y eut plusieurs rapports qui attestent la présence de pergélisol (Ives, 1962, Annerston, 1964, Brown, 1979, Nicholson, 1979, Nicholson et Grandberg, 1979).

Suite à l'installation des projets hydro-électriques et des petites villes pour les servir dans le territorie de la Baie James, il en résulte un besoin urgent pour les informations techniques et scientifiques qui portent sur la distribution de pergélisol et la profondeur et la durée du gel saisonnier dans le sol. Dans la présente étude, un essai préliminaire a été fait afin d'étudier le régime thermique du sol pour un site choisi dans le but de détecter la présence de pergélisol où il y a lieu et de décrire, et même de prédire, le régime thermique et son rapport avec le gel saisonnier du sol. Dans cette étude, une approche différente suivant Gray et al. (1974) et Singh et Gray (1980), est suggérée, si bien qu'on utilise les composantes du bilan radiatif et du bilan énergétique au lieu de la norme conventionnelle, soit la température de l'air, pour expliquer et prédire le gel dans le sol. Dans cette étude une température de 0°C dans le sol signifie le gel.

LES FLUX D'ENERGIE

Dans le cadre de cette étude on se servira des échanges radiatifs, énergétiques et calorifiques dans le système sol-atmosphère tels que résumés par les bilans qui suivent pour décrire et même prédire le régime thermique

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du sol. Etant donné que la condition thermique du sol est étroitement reliée aux échanges radiatifs, convectifs et conductifs, près de l'interface sol-atmosphère (Williams, 1974), les budgets radiatifs et énergétiques serviront à une approche convenable à la quantification et à l'application de celle-ci.

Bilan radiatif

Pour une surface plane et horizontale, il se produit des échanges continuels d'énergie radiative, entre le soleil, la terre et l'atmosphère qui, en utilisant les sigles conventionnels peuvent être décrits de la façon suivante:

$$Rn = (Q + q)(1 - \alpha) + L\downarrow - L\uparrow \quad mw\ cm^{-2} \tag{1}$$

où

Rn = rayonnement net ($mw\ cm^{-2}$)
Q = rayonnement solaire direct ($mw\ cm^{-2}$)
q = rayonnement solaire diffus ($mw\ cm^{-2}$)
α = albedo de la surface à l'étude
$L\downarrow$ = contre-rayonnement atmosphérique infra-rouge ($mw\ cm^{-2}$)
$L\uparrow$ = rayonnement terrestre infra-rouge ($mw\ cm^{-2}$).

Bilan énergétique

L'énergie rayonnante nette (Rn) captée par la surface est par la suite épuisée par les échanges turbulents entre la surface et l'atmosphère d'un côté et, de l'autre côté, par les échanges, plutôt conductifs, entre la surface et le sol au fond. Ces échanges sont résumés par le bilan énergétique, écrit comme suit:

$$Rn = LE + H + G \quad mw\ cm^{-2} \tag{2}$$

où

LE = chaleur latente turbulente de vaporisation ($mw\ cm^{-2}$)
H = chaleur sensible turbulente ($mw\ cm^{-2}$)
G = le flux de chaleur dans le sol ($mw\ cm^{-2}$).

Flux de chaleur dans le sol

La fraction du rayonnement net (Rn) qui se traduit par le processus de conduction moléculaire dans le sol se dénomme le flux de chaleur (G). Le taux d'énergie calorifique (G) qui est transmis à travers température entre la surface et une profondeur donnée dans le sol et de la conductivité thermique du sol à l'étude. Ceci s'exprime de la façon suivante:

$$G = -K \frac{(T_2 - T_1)}{(Z_2 - Z_1)} \tag{3}$$

où

G = le flux de chaleur dans le sol
T_2, T_1 = les températures de la surface (T_2) et de l'intérieur du sol (T_1) respectivement (°C)
Z_2, Z_1 = les profondeurs auxquelles T_2 (à Z_2) et T_1 (à Z_1) sont mesurées (cm)
-K = la conductivité thermique du sol à l'étude dans la direction de la diminution de la température $mw\ cm^{-1}\ °C^{-1}$).

Synthèse des échanges d'énergie

En examinant les équations 1, 2 et 3, c'est bien évident qu'il y a une interrelation étroite entre ces trois équations. L'énergie provenant des échanges radiatifs et absorbée par le sol (Rn dans l'équation 1) est partiellement utilisée pour réchauffer le sol (G dans l'équation 2). La fraction de Rn consacrée à G va dépendre des taux de LE et de H, lesquels en retour sont influencés par le type de surface à l'étude. Le taux final de G (équation 3) va dépendre des facteurs qui règlent la conductivité thermique (K) telles la minéralogie, la porosité et spécialement la concentration d'humidité du sol. L'eau dans le sol en retour influe sur la capacite volumétrique de chaleur du sol. Alors la condition thermique finale du sol à une profondeur donnée va être controlée par le taux de G qui en retour est influencé par la conductivité thermique, la diffusivité thermique et le gradient de température ($\Delta T/\Delta Z$) dans le sol.

SITE, INSTRUMENTS ET MESURES

Le site choisi pour l'expérience se trouve près de Radisson, Québec (53°, 45'N; 77°N, 15'O), sur le côté en aval du barrage LG-2. Le terrain est légèrement ondulé est il est couvert d'une végétation forestière ouverte se composant des épinettes noires et grises de 3 mètres environ, d'élévation et d'une natte de lichen d'épaisseur de 20 centimètres environ à la base. Au sol, les sédiments meubles se composent d'un couvert organique de tourbière partiellement décomposée, d'épaisseur 15 à 30 centimètres près de la surface. En-dessous de celle-ci se trouve une couche hétérogène de matière organique et minérale de couleur brun foncé, de texture de glaise ensablée et d'épaisseur de 30 à 40 centimètres. Ensuite nous trouvons successivement une couche d'argile dense de couleur brun pâle d'un mètre d'épaisseur, une couche minérale de grès grossier de 15 à 20 centimètres d'épaisseur et finalement la roche de fond à une profondeur de 2 mètres. A cause du besoin d'une prise d'électricité, le site précis était localisé à distance d'environ 300 mètres de la borne de la forêt. Alors la stipulation du bord antérieur, par rapport aux vents, et donc la représentativité de la couche turbulente, telle que recommandée par Pasquill (1972) n'était guère influencée.

Les instruments qui étaient utilisés pour mesurer ou estimer les composantes du bilan radiatif et du bilan énergétique, sauf G, étaient montés sur une tour en bois aux élévations de 3 mètres, 4 mètres et 5 mètres. Un paratonnerre était aussi installé pour protéger les instruments des orages électriques. Les mesures du flux de chaleur et de la température dans le sol étaient faits en creusant un trou de 75 cm de diamètre environ et en placant les instruments sur les côtés aux intervalles de chaque 0.5 mètre. Le trou était ensuite rempli de sédiments disposés d'une manière près à celle préalable à la perturbation.

Composantes du bilan radiatif

Toutes les composantes du bilan radiatif telles que décrites dans l'équation (1) étaient ou mesurées directement ou computées en se servant des divers instruments. Ces mesures étaient prises au niveau le plus haut (5 mètres) de la tour, une élévation qui est un peu supérieure à la hauteur moyenne des arbres. Le rayonnement global (Q + q) était mesuré directement par un solarimètre de dôme en verre blanc qui mesure dans la gamme de longueur d'onde 0.3 m à 3.0 m. L'albedo de la surface était calculé par biais à un solarimètre semblable, mais avec la surface réceptrice orientée vers le sol et ainsi mesurant le rayonnement réfléchi: $(Q + q)\ \alpha$. En prenant la proportion avec le rayonnement global, l'albedo (α) est déduit comme suit:

$$\alpha = (Q + q)\ \alpha\ /(Q + q) \tag{4}$$

Le rayonnement net (Rn) était mesuré directement par un radiomètre de marque Swissteco à dômes en polythène qui capte les longueurs d'onde de 0.3 m à 60 m. Le rayonnement terrestre infra-rouge ($L\uparrow$) était calculé par la moyenne d'un radiomètre unidirectionnel aussi de marque Swissteco. Cet instrument comprend un adapteur monté sur le côté dessus, au lieu du dôme en polythène, où est installé un thermocouple pour mesurer la correction de la température. Alors le flux $L\uparrow$ est calculé en exploitant les formules suivantes:

$$F_T = Fn + \rho T^4 \qquad (mw\ cm^{-2}) \tag{5}$$

où

F_T = le flux total d'énergie terrestrielle ($L\uparrow + (Q + q)\ \alpha$) $mw\ cm^{-2}$
Fn = le flux net entre les deux côtés du radiomètre unidirectionnel ($mw\ cm^{-2}$)
T = la température intérieure (°K) du côté supérieure de
ρ = l'appareil telle que mesurée par le thermocouple la constante de Stephen Boltzman ($0.567 \times 10^{-8}\ mw\ cm^{-2}\,°K^{-4}$,

et ainsi

$$L\uparrow = F_T - (Q + q)\ \alpha \qquad mw\ cm^{-2}. \tag{6}$$

L'autre composante du flux infra-rouge ($L\downarrow$) est calculé comme une résiduelle par biais à l'équation (1), comme suite:

$$L\downarrow = Rn - (Q + q)\ (1 - \alpha) + L\uparrow \qquad mw\ cm^{-2} \tag{7}$$

Composantes du bilan énergétique

Les composantes du bilan énergétique, telles que données dans l'équation (2) étaient calculées par le moyen de mesures directes et des formules physiques et empiriques. Le rayonnement net (Rn) était mesuré comme décrit dans la section précédente. Le flux de chaleur dans le sol (G) était mesuré à l'aide d'une plaque thermopile installée à 5 cm environ en-dessous de la surface. En raison de l'extrême difficulté d'obtenir directement les flux turbulents (H et LE), on a décidé de calculer le flux de chaleur latente (LE) en utilisant les techniques microclimatologiques conventionnelles et d'estimer le flux de chaleur sensible (H) comme un résiduel.

Deux méthodes étaient utilisées pour calculer LE. Le premier exploite le rapport (B) de Bowen (1926). Ceci peut être exprimé comme suit:

$$LE = \frac{Rn - G}{1 + B} \qquad mw\ cm^{-2} \tag{8}$$

où

B = le rapport de Bowen, $\gamma\ (\Delta T/\Delta e)$.

Dans l'expression pour le rapport de Bowen, ΔT et Δe sont les gradients de température (°C) et de pression de vapeur (mb) respectivement entre deux niveaux fixes dans l'air ambiant et γ est la constante psychrométrique avec valeur 0.66 mb $°C^{-1}$, étant donné que les psychromètres étaient ventilés.

Des thermopiles à 10 jonctions en cuivre et constantan étaient utilisés pour mesurer ΔT et Δe au-dessus de la surface végétale rugueuse, et du besoin continuel d'un bain de glace d'un fonctionnement sûr, il était décidé d'utiliser un modèle plus simple, celui suggéré par Preistley et Taylor (1972) et appelé Equilibrium et écrit comme suit:

$$LE_{eq} = \alpha' \frac{S\ (Rn - G)}{S + \gamma} \qquad \text{mw cm}^{-2} \qquad (9)$$

où maintenant

S = la pente de la courbe de la pression de vapeur saturante dépendant de la température (mb $°C^{-1}$)
et α' = un facteur de correction empirique avec valeur ici accepté de 1.26.

La valeur de α' peut varier par son rapport à la disponibilité de l'eau à la surface vaporisante (Barton, 1979; Shuttleworth and Calder, 1979). Une valeur de α' de 1.26 semble représenter les conditions d'évaporation potentielle. Etant donné que la période d'étude correspondait du début de l'automne quand la demande évaporative de l'atmosphère et, donc, la tension sur l'eau dans le sol était réduite, et que la période était caractérisée par une pluviosité assez élevée, il a été décidé d'adopter cette dernière valeur. D'ailleurs cette valeur de α' (1.26) semble être entièrement représentative tel que démontré pour d'autres études portant parfois sur une semblable couverture végétale et parfois sur un pareil climat régional (McNaughton and Black, 1973; Davies and Allen, 1973; Thompson, 1975; Stewart and Rouse, 1977; Mukammal and Newman, 1977; Williams et al., 1978).

De plus, nous avons calculé LE_{eq} en acceptant une valeur de α' de 1.26 et nous avons comparé les valeurs trouvées avec celles exploitant le rapport de Bowen (B) et les résultats sont assez bons (fig. 1).

Composés du flux de chaleur dans le sol

Les mesures du flux de chaleur (G) dans le sol ont été obtenues par le moyen de plusieurs plaques thermopiles. Un de ces instruments était placé près de la surface et les autres étaient installés à chaque 0.5 mètres jusqu'à la roche en place (2.0 mètres). A ces mêmes profondeurs étaients placés des thermocouples en cuivre et constantan pour détecter la variation de la température du sol.

Tous les signaux des divers instruments étaient branchés à un enregistreur automatique digital (Fluke 2240B) qui fut équipé d'un point de référence électronique pour les thermocouples. Pendant la première étape de l'étude (du 1er au 23 septembre 1978), les données furent recueilliées à chaque 10 minutes. Cependant, à cause du manque de personnel, les données furent prises moins régulièrement pendant les autres périodes, soit à chaque heure, du 10 octobre au 27 novembre, 1978 et aux intervalles de 4 heures, du 10 janvier au 25 avril, 1979.

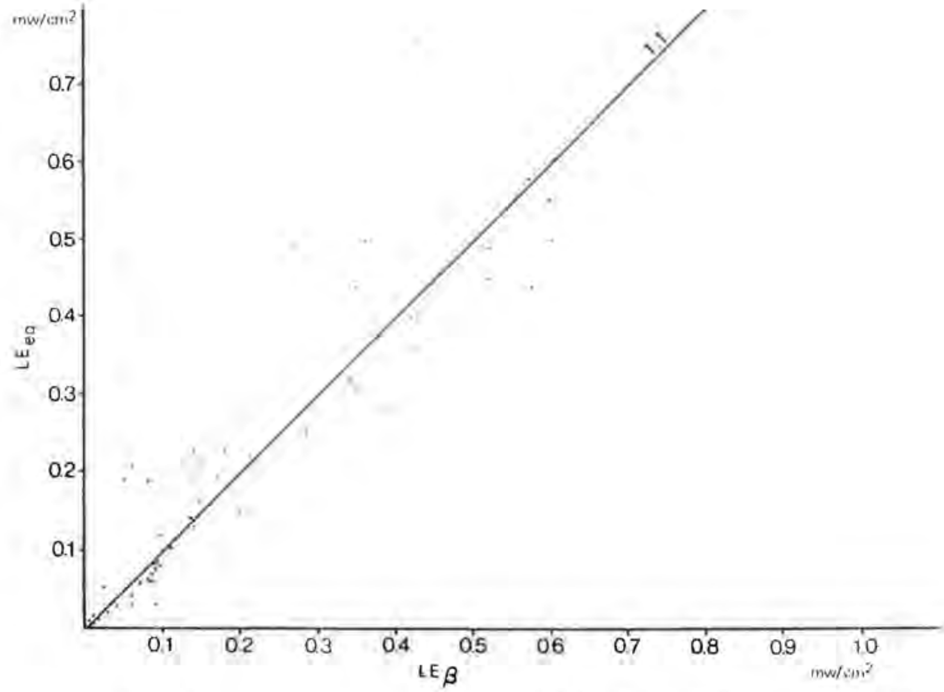


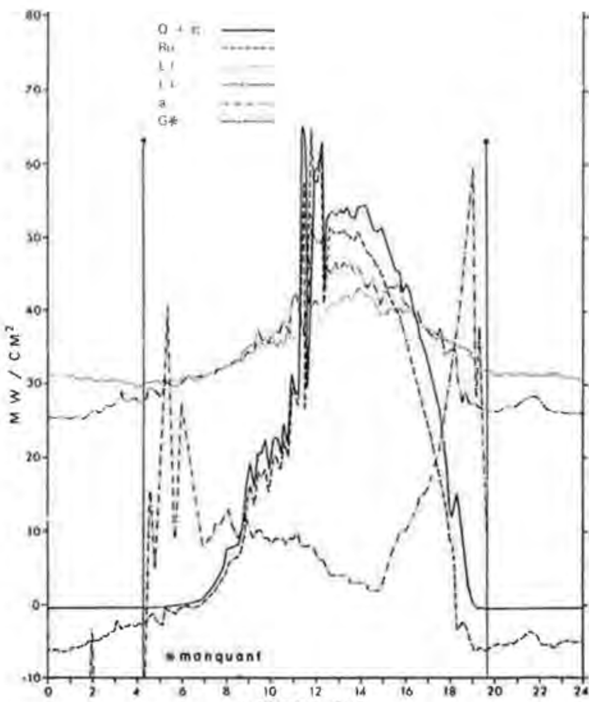
Fig. 1. Relation entre LE_{EQ} et LE_{B}, 7 et 18 septembre 1978.

RESULTATS

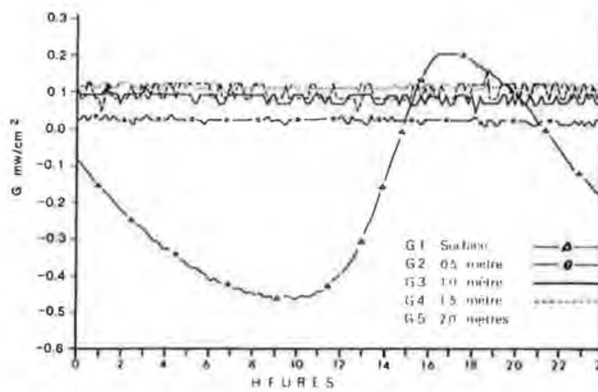
Les résultats de l'expérience seront présentés de la façon suivante. D'abord des journées représentatives à l'intérieur de chacune des périodes citées ci-dessus seront choisies pour décrire la répartition du bilan radiatif et du bilan énergétique, le comportement journalier de leurs composantes et leurs rapports avec le régime thermique du sol. Ensuite, quelques-uns de ces paramètres seront utilisés pour prédire la température du sol.

Relations entre le bilan radiatif et énergétique et la température du sol

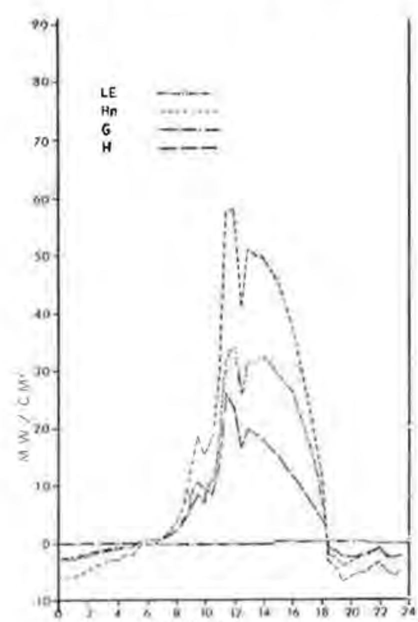
Les résultats de la première période de l'étude sont bien représentés dans la figure 2 (18 septembre, 1978). En ce qui concerne le bilan radiatif, les points suivants doivent être soulignés. Comme prévu et tel que prouvé plus tard, il existe une relation assez forte entre le rayonnement global (Q + q) et le rayonnement net (Rn). La courbe de l'albedo est aussi typique avec les valeurs plus élevées près du lever et du coucher du soleil et les valeurs plus basses autour de midi. Les fluctuations, spécialement le matin, étaient dûes à l'ombrage de l'instrument par des ombres voisinantes. De plus, il y avait eu une légère chute de neige la nuit précédente, suivi des conditions nuageuses le matin suivant (voir (Q + q) et Rn). Ceci a provoqué une hausse de la valeur de l'albedo, soit de 0.4 environ. Avec la fonte éventuelle de la neige au cours de la matinée, il y avait eu libération de l'eau fondue qui en retour a fait baisser l'albedo à 0.12 environ. La hausse de la concentration d'eau dans le sol a probablement augmenté la conductivité thermique du sol et alors le flux de G (fig. 2c). Les échanges infra-rouges sont presque pareils pour la plupart de la



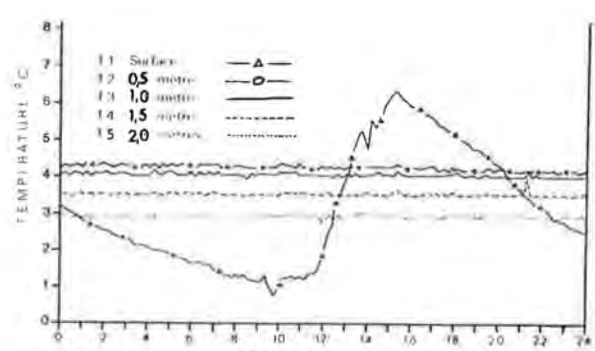
(a) Composantes du bilan radiatif



(c) Flux de chaleur dans le sol

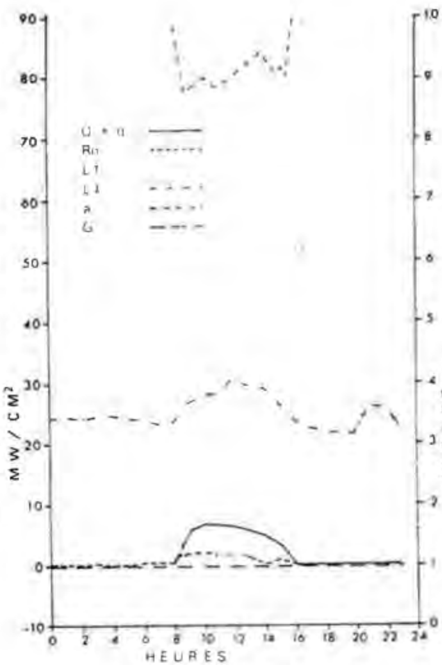


(b) Composantes du bilan énergétique

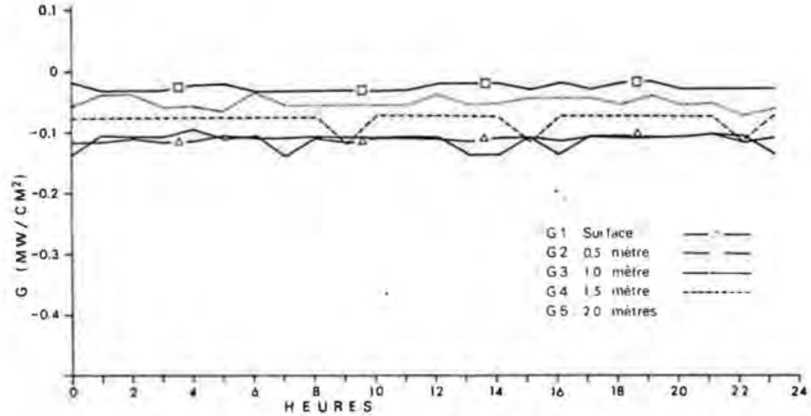


(d) Température du sol

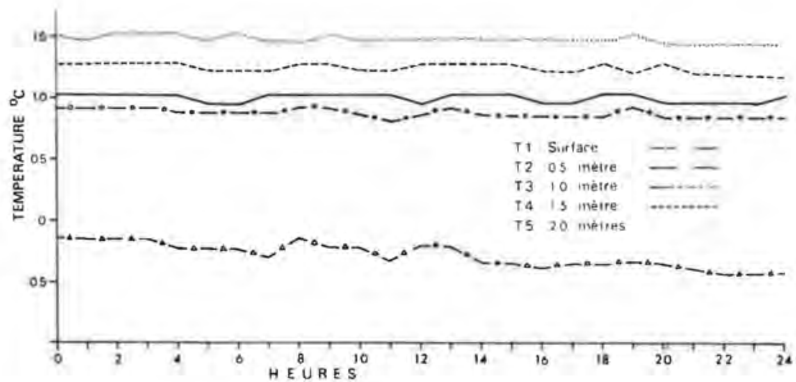
Fig. 2. Les conditions du 18 septembre, 1978



(a) Bilan radiatif et bilan énergétique



(b) Flux de chaleur dans le sol



(c) Température du sol

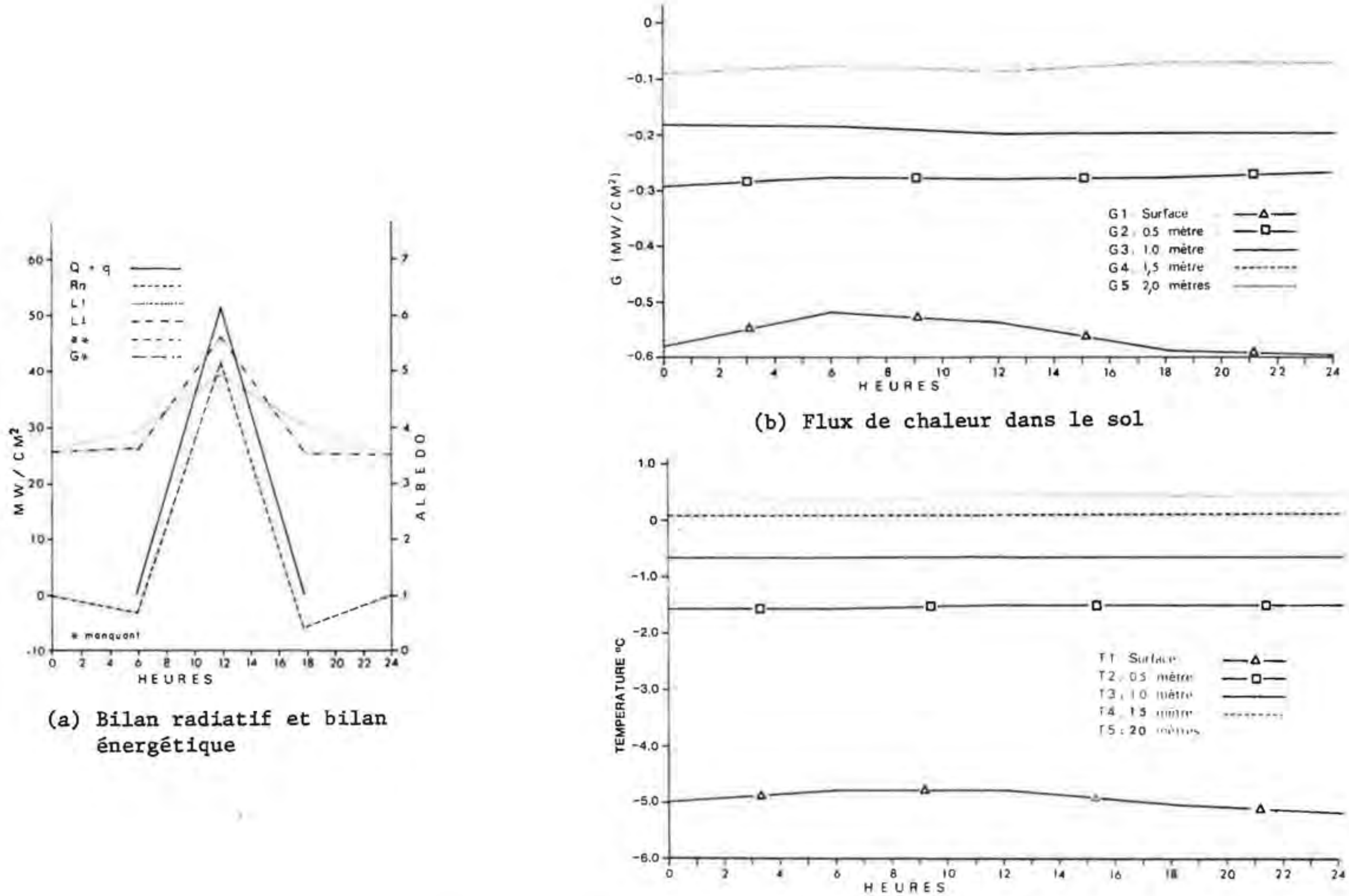
Fig. 3. Les Conditions du 26 novembre, 1978.

journée. Néanmoins, il semblait que L↓ était plus élevé que L↑ le matin. Cette condition est bien anormale et il apparait que la valeur de L↑ était sous-estimée pendant la période d'ensoleillement en raison de la réception des rayons sur le dessus de l'instrument. Cette condition a très probablement réduit Fn et ensuite L↑. Etant donné que L↓ est calculé comme résiduel, cette sous-estimation de L↑ possiblement causé la sur-estimation de L↓. Toutefois, pendant la nuit, dans l'absence de rayonnement solaire, les valeurs des échanges infra-rouges sont plus réelles avec L↑ plus élevé que L↓ et avec le résultat que Rn soit négatif.

La répartition de Rn était ensuite effectuée comme décrite dans la figure 2b. En faisant l'intégration des valeurs, Rn (100%) est réparti comme suit: H (38.1%), LE (62.6%) et G (-0.7%) étant donné que le flux de G près de la surface était négatif pour la plupart de la journée. Cette dernière condition est très typique pour cette période de l'année quand l'air et la surface se refroidissent. Il semblait aussi avoir un délai d'environ quatre heures entre la réception maximale du rayonnement solaire (midi) et le flux positif maximal de G à 5 cm dans le sol (figs. 2a, 2b et 2c). Ceci est évidement dû au fait que la température maximale de la surface se produit vers quatre heures de l'après-midi. Pour cette période de l'année le flux de G est faiblement positif partout au fond du sol et même parfois négatif près de la surface où la variation journalière du rayonnement solaire se faisait sentir (fig. 2c). Cette condition est reflétée dans les températures du sol (fig. 2d). Il y avait une diminution générale de la température d'après la profondeur: la température à la surface étant soumise à la variation journalière de rayonnement variant entre 6°C le jour et à 1°C la nuit, et ensuite il y avait une diminution graduelle de 4.2°C à 0.5 mètre jusqu'à 3°C à 2 mètres. Néanmoins pour la date à l'étude il y avait absence de gel partout dans le sol.

Pour la deuxième et la troisième étape de la recherche nous n'avons pas calculé les flux turbulents d'énergie (H et LE), ceci étant dû à la difficulté d'accueillir les mesures pertinentes. De plus, pendant l'hiver quand la température de la surface et de l'air sont moins de 0°C, presque tout du rayonnement net (Rn), déjà très faible, est utilisé pour le transfert de chaleur sensible (H) (OKE, 1978). Alors vers la fin de la deuxième période de l'étude (voir fig. 3a, 3b et 3c), l'intensité du rayonnement global (Q + q) tel que prévue, est faible. Par surcroît, la valeur de l'albedo est très élevée, soit de 0.9 environ. Ceci est entendu étant donné que l'accumulation totale de la neige était de 100 cm environ. De plus, l'échange infra-rouge est négatif (L↑ > L↓) pendant le jour. Tous les facteurs ensemble rendent l'intensité du rayonnement net (Rn) très faible le jour, déjà de courte durée, et négative la nuit (fig. 3a).

Cette condition d'échange d'énergie à la surface amène à la perte de chaleur dans le sol. Ceci est évident dans la fig. 3b où le flux de chaleur (G) est négatif partout avec la perte plus élevée se trouvant à 1 mètre et près de la surface. Un autre fait intéressant est qu'étant donné les températures dans le sol près de 0°C, il semblait y avoir des fluctuations abruptes de G. Ceci peut être attribué à la relâche de chaleur latente avec changement de phase de l'eau de liquide à solide à cette température critique. A noter aussi, l'absence du cycle diurnal de G près de la surface dans la présence d'une couche de neige assez épaisse. La perte de chaleur (G négatif) est vérifiée par le profil de la température du sol (fig. 3c). A cette période, le profil thermique était maintenant renversé; il y avait une hausse de la température d'après la profondeur augmentant de 1.5°C à 2 mètres jusqu'à -0.3°C à la surface. Alors le gel s'était maintenant installé dans



(a) Bilan radiatif et bilan énergétique

(b) Flux de chaleur dans le sol

(c) Température du sol

Fig. 4. Les Conditions du 25 février, 1979

la couche de sol entre 0.5 mètre et la surface.

Pendant la période de plein hiver (fig. 4) le rayonnement global (Q + q) et le rayonnement net (Rn) sont de nouveau assez élevés, étant donné l'altitude du soleil. Malheureusement nous manquons les valeurs de l'albedo. Alors la haute valeur de Rn pendant le jour peut être attribuée à l'échange infra-rouge ($L\downarrow > L\uparrow$), laquelle condition suggère la présence d'une masse d'air relativement chaud en altitude.

Le régime thermique du sol démontre que l'intensité du flux de chaleur dans le sol dans le sens négatif était maintenant la plus élevée, (fig. 4b). Aussi, il semblait que le flux près de l'interface (G_1) commençait à être influencé par la hausse dans la réception du rayonnement solaire. Ceci est aussi évident dans la température dans le sol (TS_1) (fig. 2c). La température à 2 mètres était de 0.5°C et elle diminuait jusqu'à -5°C environ à la surface. Le gel se trouvait maintenant entre la surface et une profondeur de 1.5 mètres.

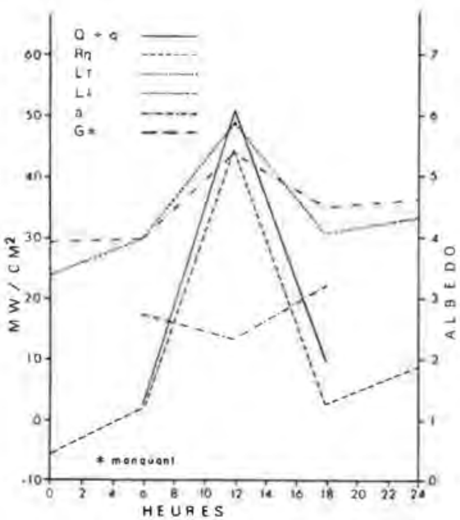
Vers la fin de l'hiver (fig. 5a, 5b et 5c) qui correspondait à la période de la fonte de la neige, la réception du rayonnement global (Q + q) continuerait à grimper. Le rayonnement (Rn) était maintenant aussi très élevé étant donné l'albedo de la surface qui était drastiquement réduite (fig. 5a). Le flux de chaleur près de la surface était maintenant positif en réponse à la hausse en Rn et à la disposition presque complète de la couche neigeuse. Au fond, dans le sol, les flux demeuraient moins négatifs et il semblent être influencés par le changement de phase de l'eau et par la pénétration de l'eau libérée par la fonte de la neige (fig. 5b). Cette décharge d'eau dans le sol semblait rendre les températures presque uniformes partout dans le sol où les températures, au moins au fond, se trouvent près de 0°C. A noter, le gel n'a jamais pénétré jusqu'à 2 mètres dans le sol.

Prédiction du gel dans le sol

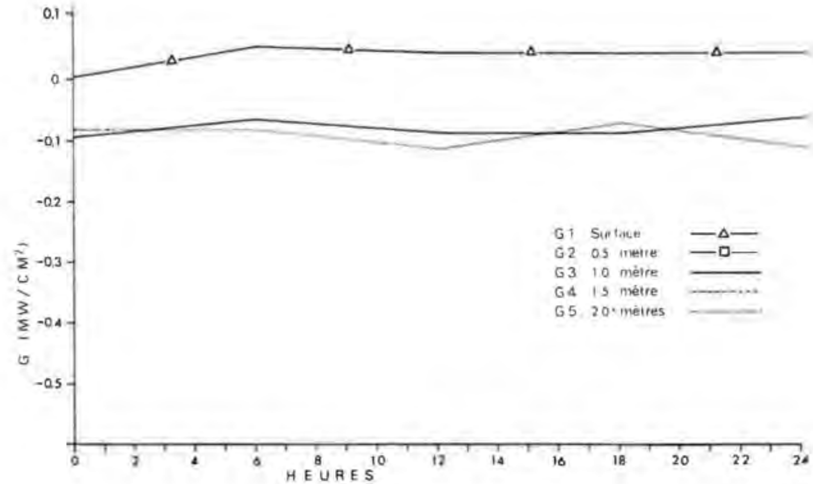
Dans cette section on essaiera de prédire d'une façon préliminaire le régime thermique et ainsi le gel dans le sol à partir d'un rayonnement net (Rn) ou d'un rayonnement global (Q + q). C'est bien évident dans la figure 6 qu'il existe une relation assez forte entre Rn et (Q + q). Cette relation appuie les résultats prouvés ailleurs (Davies, 1967, Fritschen, 1967 et Polavarapu, 1970). De plus, la relation devient de plus en plus forte quant on accumule les valeurs brutes pour donner les totaux de jour et ensuite les totaux accumulatifs. Ceci est essentiellement dû au fait que les écarts des valeurs instantanées ou même journalières sont réduites quand celles-ci sont cumulées.

Tel que démontré dans la section précédente, il existe une relation forte entre le rayonnement net (Rn) et le flux de chaleur (G) et aussi la température (T_1) du sol. Ceci est aussi vrai sur une échelle annuelle (fig. 7). Dans la figure 7 les valeurs maximales de Rn, G, T_s ainsi que de la température de l'air ambiant (T_a), pour des journées choisies, sont tracées. Il apparaît que le comportement de G et de T_s suit étroitement celui de Rn et jusqu'à un certain point celui de T_a.

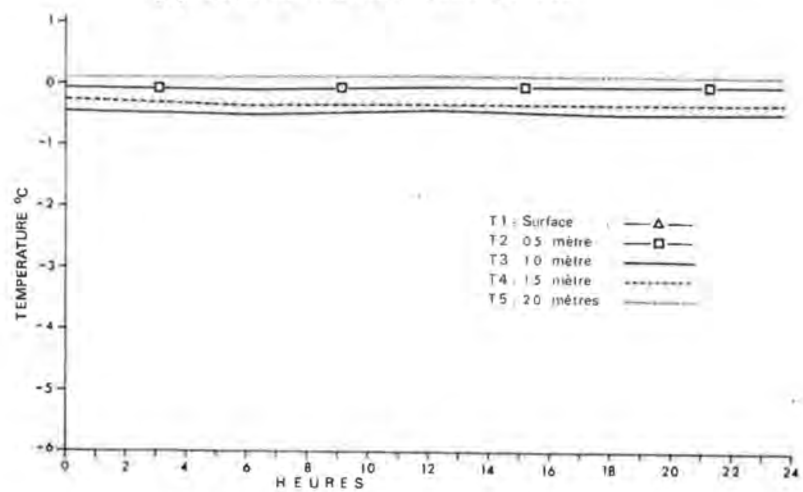
Alors il est vraisemblable qu'on peut prédire le flux de chaleur dans le sol (G), à partir du rayonnement net (Rn) et ensuite la température (T_s) dans le sol à partir de G. Utilisant des valeurs cumulatives, la relation entre Rn et G_1 (près de la surface) est démontrée dans la figure 8.



(a) Bilan radiatif et bilan énergétique



(b) Flux de chaleur dans le sol



(c) Température du sol

Fig. 5. Les Conditions du 20 avril, 1979.

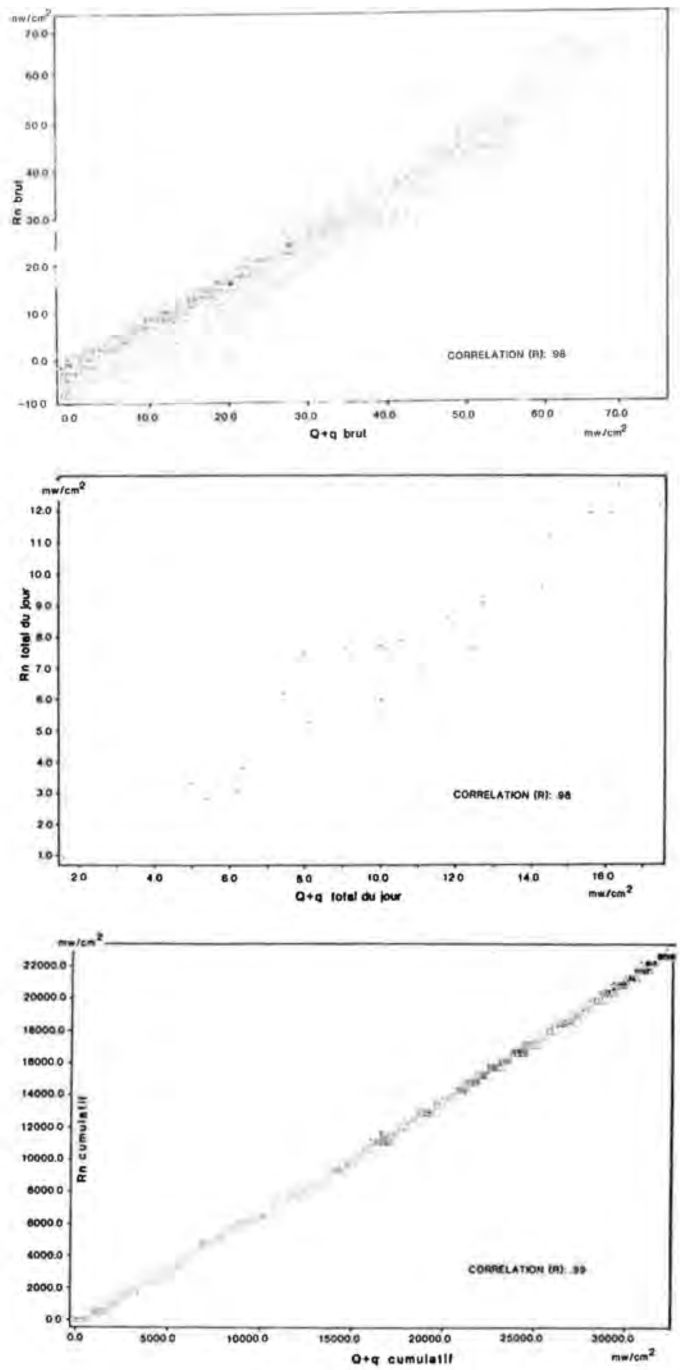
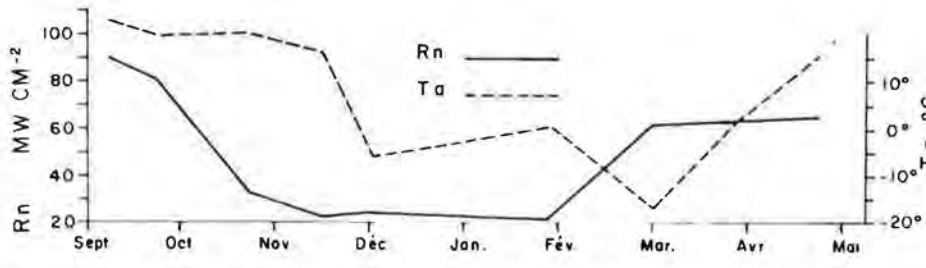
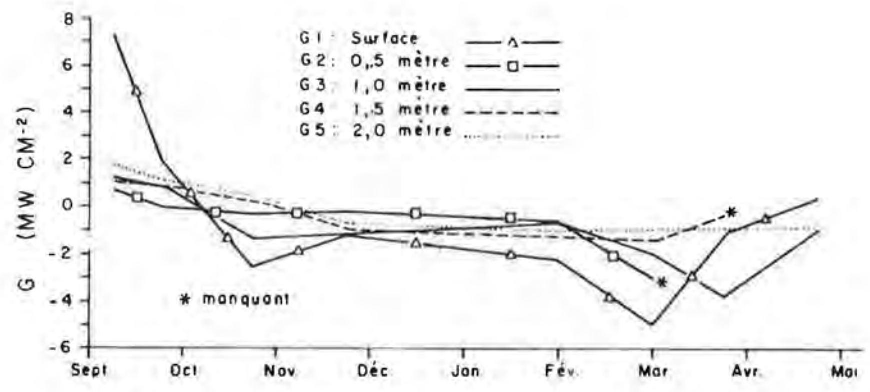


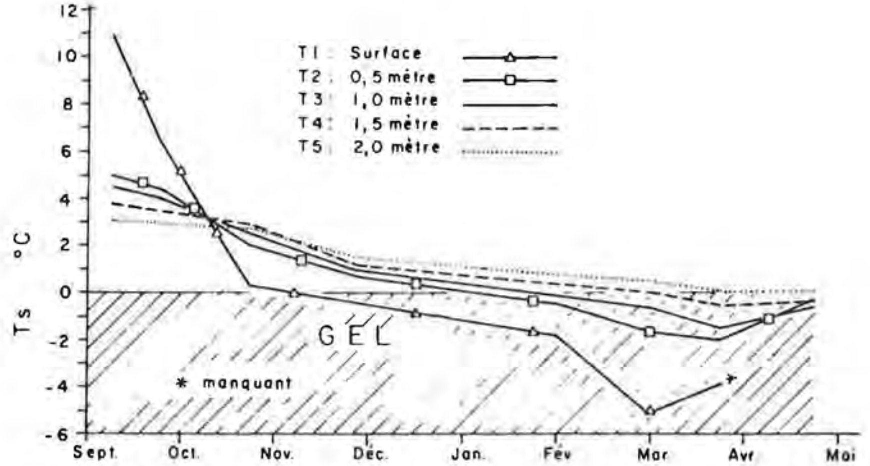
Fig. 6. Les Relations entre le rayonnement global et le rayonnement net: 1-23 septembre, 1978.



(a) Rayonnement net et la température de l'air



(b) Le flux de chaleur dans le sol



(c) La température du sol

Fig. 7. Variation annuelle des éléments: 1978-1979.

Dans la figure 8a, on considère le début de l'automne et où le flux de G_1 commence à se diriger vers l'interface on peut-voir que la corrélation est passablement forte et positive. La raison pour la corrélation passablement forte est que la cumulée de G_1 peut varier selon la direction (positif ou négatif) de G_1. Toutefois, vers le début de l'hiver la corrélation est très forte, mais maintenant négative, étant donné que le flux de G_1 est essentiellement dirigé vers l'interface (fig. 8b). Cette tendance se continue jusqu'à la fin de l'hiver où l'augmentation de Rn et l'enlèvement de la couche neigeuse commencent à rendre G_1 positif, et donc la courbe asymptotique de la figure 8c.

Sûrement, la prochaine étape logique sera de relier T_{s1} à G, et finalement T_{s1} à Rn. Ceci se fait dans les figures 9a et 9b où on considère les résultats du 10 octobre au 27 novembre. On voit que les relations même ne sont pas assez fortes, elles donnent des résultats encourageants. Dans la figure 9a il semblait qu'au début de la période, la relation était positive et passablement forte; le cumul de G_1 et de T_{s1} étant positif. Ensuite, la relation est renversée: le cumul de G_1 est négatif, laquelle condition est typique pour la période à l'étude, alors que la température dans le sol continue à garder au-dessus de 0°C. Par après, G_1 continuait à être négatif et T_{s1} fluctuait très peu, la variation de la température du sol à ce niveau étant tamponnée par la couche de neige et la relâche de chaleur du fond.

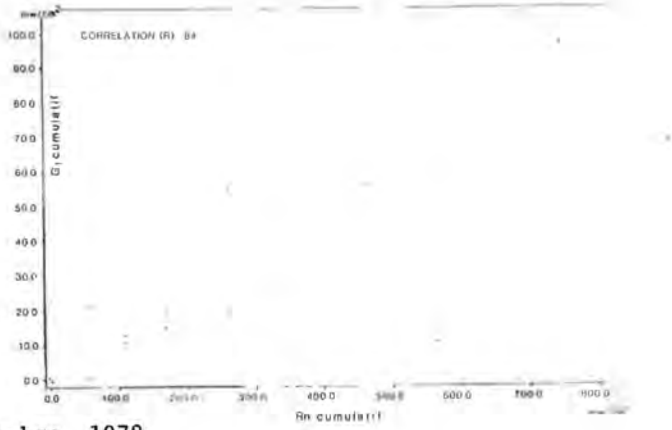
Finalement dans la figure 9b il semblait qu'au début de la période Rn cumulé fluctuait très peu par rapport à T_{s1}, étant donné que Rn positif de jour s'était annulée par le Rn négatif de nuit. Néamoins, après l'installation de la couche neigeuse c'était T_{s1} qui fluctuait peu par rapport à Rn parceque les variations de T_{s1} étaient maintenant tamponnées par la couche neigeuse.

Conclusions et recommandations

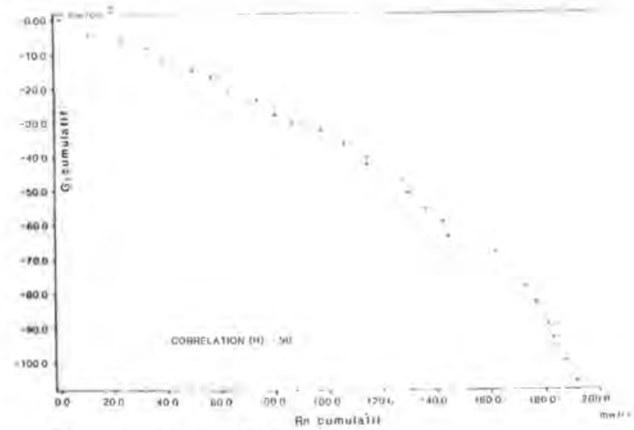
C'est bien évident dans cette étude que les résultats même provisoires, sont encourageants en ce qui concerne la prédiction du gel dans le sol à partir de mesures d'un rayonnement net (Rn) ou rayonnement global (Q + q). De plus, on peut négliger les échanges infra-rouges d'énergie rayonnante; les deux composantes (L↑ et L↓) s'annulent pour la plupart du temps. Il semble aussi que ces mesures (Rn et Q + q) sont plus étroitement reliés au régime thermique du sol que la température de l'air, facteur soumis aux caprices de déplacements de masses d'air. Dans la présence d'une couche de neige la température du sol est moins susceptible à ces conditions atmosphériques.

Néanmoins, il exists plusieurs faiblesses dans les résultats décrits ci-dessus et il y a plusieurs raffinement à y apporter. Premièrement, toutes les corrélations présentées sont linéaires, bienqu'il est évident les relations semblent être parfois non-linéaires. De plus, le fait que le régime hydrique du sol n'était guère étudié au même temps affaiblit quelques-uns des résultats.

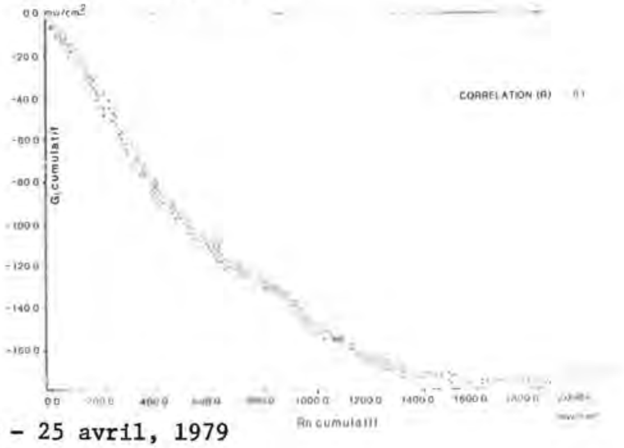
Dans le but de corriger quelques-unes de ces faiblesses, le site de recherche fut déménagé au camp du Lac Hélène où la profondeur des dépôts meubles atteignait 7 mètres environ. De plus, plusieurs types de site, soit une zone brûlée, une tourbière, un site défriché et une route pavée étaient aussi considérés. Aussi, la concentration d'eau dans le sol a été mesurée régulièrement. On est en train d'analyser les résultats de cette expérience et on espère développer toute une série d'équations physico-empiriques pour prédire le gel dans le sol à partir de (Q + q) et Rn, pour plusieurs



(a) 1-23 septembre, 1978

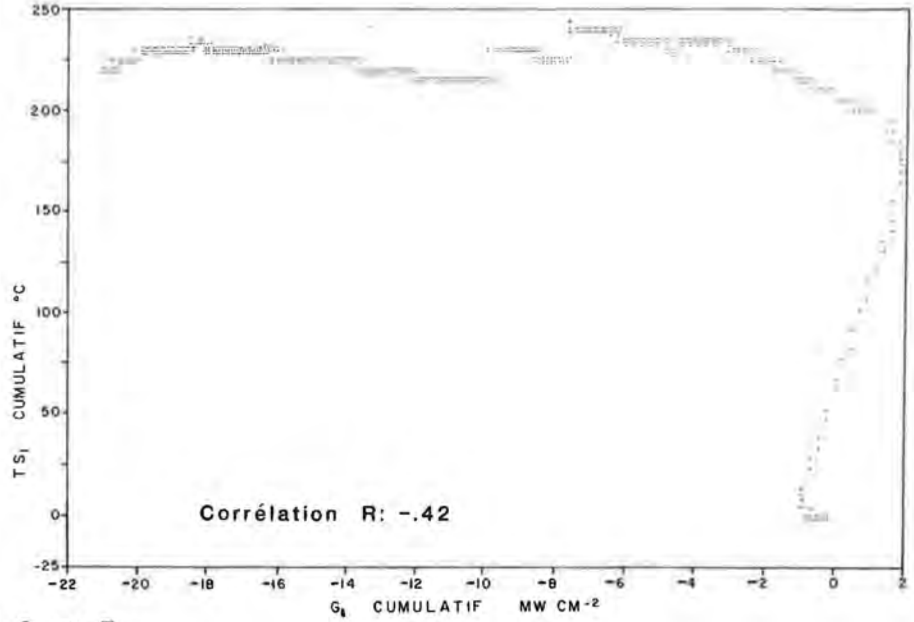


(b) 10 octobre - 27 novembre, 1978

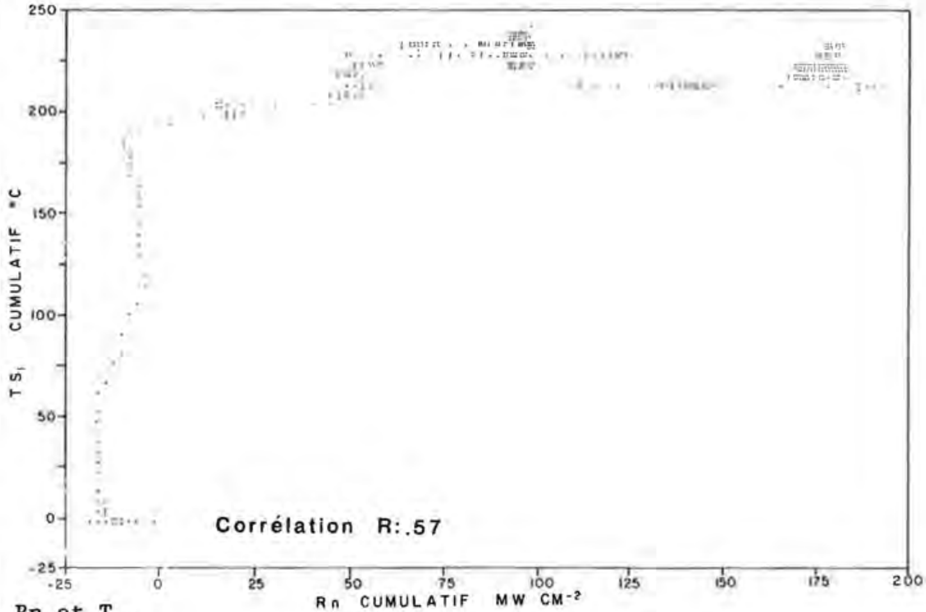


(c) 10 janvier - 25 avril, 1979

Fig. 8 Les Relations entre Rn cumulatif et G_1 cumulatif



(a) G_1 et T_{s1}



(b) Rn et T_{s1}

Fig. 9 Les conditions cumulatives: 10 octobre - 27 novembre, 1978 profondeurs dans le sol. On prévoit se servir des autres variables pertinentes soit la concentration d'eau dans le sol, l'épaisseur de la couche neigeuse et la température de l'air ambiant. Ces résultats seront présentés prochainement.

Remerciements

L'auteur aimerait remercier le CRSNG et le CINEP pour l'aide financière apportée à la conception de ce rapport, et la SDBJ et la SEBJ pour avoir défrayé le logement et le transport sur le terrain pendant les expériences.

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CLIMATOLOGY AT THE 24th INTERNATIONAL GEOGRAPHICAL CONGRESS

by

Stanton E. Tuller*

The main session of the 24th International Geographical Congress was held in Tokyo, Japan on August 31 - September 5, 1980. Following the practice of a number of other recent Congresses, the climatology session was a part of Section 2 along with hydrology and oceanography. Glaciology which had been included in the section with climatology in some previous Congresses was combined with geomorphology to form Section 1 at Tokyo.

Each of the subsections of Section 2 were given a separate letter designation and constituted a discrete entity at the 24th I.G.C. The subsections were scheduled on succeeding days so that a person with a great deal of interest and stamina could have attended all of the papers in Section 2. Given the overriding importance of climatology it is not surprising that the climate subsection was designated Section 2A and was held on the first day of formal papers; Monday, September 1. The Section 2 programme was convened and arranged by Takeshi Kawamura of the University of Tsukuba who also presented a paper on urban climatology in Section 2A.

Twenty-six papers were scheduled on the programme of the climatology section. One to two page abstracts of 19 of these papers were published in the preprint volume and 15 papers were actually presented. This is somewhat less than the number of climatology papers presented at the Montreal and Moscow Congresses, although the assignment of papers to sections makes a precise comparison impossible.

A wide variety of subject areas were represented by the papers included in the programme. The dominant themes were the discussion of the precipitation climate of different areas (6 papers scheduled, 4 given) and urban climatology (5 papers scheduled, all of which were given). Other topics covered in the papers actually presented at the meeting were: agricultural climatology, severe storms, air temperature and water balance.

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In general, about two-thirds of the papers could be categorized as addressing applied topics and the majority of the remainder were concerned with some aspect of regional climatic description. Empiricism was dominant. No paper either scheduled or presented in Section 2A could be considered to be purely theoretical. Four or five papers involved some aspect of mathematical or simulation modelling. Even these papers, however, had a strong empirical basis.

In summary, if a major international congress is assumed to attract papers which represent the current trends in research in a discipline, the programme of the 24th I.G.C. revealed that there have been no dramatic recent shifts in major areas of emphasis in climatology. Geographical climatologists for the most part are still investigating the same topics, largely using the same methods that have been popular over the last few years. The subjects of the papers submitted to the 24th I.G.C. by participants from around the world were the same as those of papers given at national and regional meetings of the Canadian Association of Geographers or the Association of American Geographers. One was not exposed to any marked new innovation or area of research which might be developing in some other part of the world. To be sure, several interesting ideas and approaches were introduced, but no well-defined trend toward any new subject areas or techniques, developed since the Moscow or Montreal Congresses, was evident in the programme of the Tokyo meetings.

Japan and Canada were the two countries best represented by the authors of the papers scheduled and presented in the climatology section of the 24th I.G.C. Four papers were presented by contributors from Canada. These included:

"Analyse multivariée des types de temps," by A. Hufty (Université Laval);

"Simulation of nocturnal heat island development in cold chamber experiments: The role of radiation geometry," by T.R. Oke (U.B.C.);

"Some aspects of the urban long wave radiation regime in cities of moderate size," by S.E. Tuller (University of Victoria); and

"A longer growing season in the face of declining mean annual and summer temperatures: A paradox of an upper middle latitude climate," by L. Nkemdirim (University of Calgary).

Another notable Canadian contribution was Marie Sanderson's deft job of juggling the no-shows and late arrivals to produce a well-run programme as chairman of the morning session amid the confusion of the first full day of the main session of the Congress.

One highlight of all sections of the Congress was the large number of papers on Japan itself. These were very interesting and valuable for both those geographers with a special interest in Japan and those who just filled the role of curious tourists eager to learn more about the country they were visiting. Four papers concerning Japan were presented in the climatology section. Two of these looked at the urban climates of two important Japanese cities: Tokyo (T. Kawamura) and Hiroshima (Y. Fukuoka). The other two described regional precipitation patterns. Heavy rainfall in central Honshu was discussed by M. Mizukoshi and snowfall on the Japan Sea coast by M. Shitara.

Each session was chaired by at least one Japanese and one foreigner. The basic idea behind this strategy was to facilitate any translation which might be needed during the question periods. In the end, however, all Japanese speakers and questioners had a very good command of English and no translation was needed.

Other countries represented by papers actually presented in Section 2A (including multi-author papers) were Nigeria, West Germany, South Africa, New Zealand, the U.S.S.R., and China.

A second feature of the main session of the 24th I.G.C. which had appeal for the climatologist was the General Symposium on Climatic Change and Food Production, held on Tuesday, September 2. Papers in this session addressed not only several aspects of climatic change and its possible effects on food supplies but also some of the resultant social problems, and the difficulties of actually determining food production in many areas of the world. The majority of the papers were concerned with Monsoon Asia or Africa but other areas of the world were covered as well. B. Dey submitted a paper on "Impact of climate on variations in summer ice cover in the Canadian Arctic" and T.R. Oke chaired one of the morning sessions of this symposium.

As usual in a large meeting there were a number of papers in other sections which had some climate content and would have been of interest to the climatologist. However, anyone who attended the sessions on geomorphology and glaciology, hydrology, and biogeography; the General Symposium on Natural Disasters as Environment; the meeting of the working group on Tropical Climatology and Human Settlements and W. Meckelein's public lecture on "Desertification - The main problems of desert oases today," would have had no time to drink green tea, soak in a hot bath or sample the other delights of Japanese culture. In the final analysis, despite the wide variety and generally high level of climatology papers presented at the meetings, the highlight of the 24th International Geographical Congress was the opportunity to experience Japan and the Japanese way of life first hand.

Acknowledgement

Marie Sanderson and Tim Oke supplied useful information concerning the papers presented in the Section 2a session during the times when the author of this report was out of the room drinking green tea. Their aid is gratefully acknowledged.

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NEWS AND COMMENTS

The Meteorological Society of New Zealand (Inc.) was inaugurated at a meeting held on 11 October 1979. The Society has now published the first number of its journal (Vol. 1, No. 1, February 1981) which is to be produced twice a year, in February and August.

This first number included an editorial, "The Economic Climate" by the journal's editor W.J. Maunder, five main articles, and a number of book reviews.

The Society's journal is called Weather and Climate and contributions are invited on any meteorological or climatological subject, but preference will be given to contributions related to New Zealand and/or the South West Pacific area. Articles for publication should preferably be about 2000 words in length.

The Editor of Weather and Climate is:

Dr. W.J. Maunder, N.Z. Meteorological Service, P.O. Box 722, Wellington, New Zealand.

The Proceedings of the 1980 Annual Meeting of the Alberta Climatological Association, held in February 1980, have been published by the Alberta Energy and Natural Resources Department. The Proceedings contain a report on the activities of the Association, together with individual reports covering the wide range of climatological activities of government departments, universities, and other organizations in Alberta. At the same time as the annual meeting, a workshop on water resources was held under the auspices of the Canadian Climate Centre.

Persons interested in the proceedings of the Association should write to:

K.R. Leggatt, Resource Evaluation Branch, Alberta Energy and Natural Resources, 4th Floor, North Tower, Petroleum Plaza, 9945 - 108 Street, Edmonton, Alberta, T5K 2C9.

For information on the water resources workshop and proceedings, inquiries should be addressed to:

Canadian Climate Centre, 4905 Dufferin Street, Downsview, Ontario M3H 5T4.

The 1981 Workshop and Annual Meeting of the Alberta Climatological Association was held at the University of Alberta on February 26, 1981. The theme of the workshop was: "Climate Change and Variability and Their Impact on Alberta's Resources and Environment".

A Workshop on Climatology in Quebec was held in Montreal in October, 1980, at the local headquarters of the Atmospheric Environment Service. Twenty-five persons participated in the workshop representing government, universities, and hydro-Québec. Gordon McKay presented a description and analysis of the world climate program and the part being played by Canada in it. This was followed by a series of presentations outlining the program and work of federal and provincial climatologists in Quebec, together with a review of work in climatology at the University of Laval, University of Sherbrooke, University of Montreal, and the University of Quebec at Montreal and at Trois Rivières. Unfortunately there was no participation from McGill University due to John Lewis and Ben Garnier both being out of the country on sabbatical leave and the time of the workshop.

After the foregoing presentations, there was a general discussion on climatology in Quebec under the chairmanship of Pierre Ducharme, AES, Montreal. The discussion centred on ways of bringing climatologists closer together through some form of association and publication procedures, and ensuring full participation of climatologists in the province in the Canadian climate program. A group of four persons - Béatrice Félin, Joseph Litynski, Michel Ferland, and Pierre Ducharme - was set up to examine the various suggestions put forward in the discussion and report back to the participants in the workshop within six months.

The following note on "An Assessment of Cloud Seeding" has been supplied by Professor R.W. Longley:

> "At the request of the Research Council of Alberta, Richmond W. Longley and Raymond K.W. Wong examined data related to the 25 summers of seeding clouds in south central Alberta. Their report, presented to the Research Council, finds no clear evidence that the hail damage has been reduced because of the seeding. The decline in the loss/risk ratio over the seeded area between 1955 and 1970 was matched by a similar decline in an area to the north. This latter area had an increase in the L/R ratio in the 1970's although cloud seeding was extended to cover the area during that period.
>
> The rainfall on the area of cloud seeding was compared to a control area of western Saskatchewan. The examination showed no significant change in the precipitation on the area where clouds were seeded."

McGill University

Department of Geography

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