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CLIMATOLOGICAL BULLETIN

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SOME EFFECTS OF MULTIPLE REFLECTIONS BETWEEN GROUND AND SKY

by

Hardy B. Granberg*

Introduction

Several authors have shown that multiple reflections between ground and sky influence the incoming diffuse radiation (e.g. Chandrasekhar, 1950; Chandrasekhar and Elbert, 1954; Deirmendjian and Sekera, 1954; Fritz, 1955; Coulson et al., 1960). Yet, numerous studies may be found where the effects of multiple reflections between ground and sky have not been appreciated. In many cases the results of the investigations have suffered accordingly.

This paper should be seen as an attempt to explore and illustrate some effects of multiple reflections rather than as an attempt to provide a predictive numerical model of their influence. A computer simulation model is used to examine some of the effects of multiple reflections over surfaces of different albedo under different sky conditions. Some of these effects cannot easily be studied by measurement due to the difficulties involved in determining the optical properties of the sky. While the model is extremely simple and ignores many important aspects of the actual physical processes involved, it is thought that some limited but basically valid conclusions may be drawn from the simulations.

The Simulation Model

A shortwave radiometer measures (Q+q) where Q represents the direct beam solar radiation and q represents the diffuse shortwave radiation incident on a horizontal surface. The diffuse radiation results

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from both scattering of the incoming beam and backscatter of radiation already reflected by the ground surface. We may write

$$(Q + q) = (Q_B + Q_M) \tag{1}$$

where Q_B represents the more or less strongly diffused radiation that reaches ground level after its initial path through the atmosphere. Part of this radiation is absorbed at the surface and the rest is reflected. Some of this reflected radiation escapes back into space but some is reflected back towards the surface again by the sky. The cycle may be repeated several times until eventually all radiation has either been absorbed by the ground surface or escaped back into space. In equation (1), Q_M represents the downward component added by such multiple reflections between ground and sky. If we designate the part of Q_B reflected by the ground surface as Q_{BG1} the first time it is reflected and Q_{BG2}, Q_{BG3} ... Q_{BGN} in the subsequent reflections and, in a similar fashion, the part reflected downwards by the sky as Q_{BS1}, Q_{BS2}, Q_{BS3}... Q_{BSN} then

$$Q_M = \sum_{i=1}^{N} Q_{BSi} \tag{2}$$

and

$$Q_R = \sum_{i=1}^{N} Q_{BGi} \tag{3}$$

where Q_R is the reflected radiation that would be measured by a down-facing radiometer. A standard up-facing radiometer samples radiation both from Q_B and from the different orders of sky reflection within Q_M. Thus, at any instant it measures radiation that entered the atmosphere over a short time interval. The observed radiation at the ground surface is therefore greater than the radiation actually transmitted by the atmosphere.

Evaluation of Q_B and Q_M

The radiant flux through a horizontal surface at the top of the atmosphere, Q_o, is a function of the zenith angle of incidence, θ, such that

$$Q_o = \cos \theta C \tag{4}$$

where C is the solar constant. The angle of incidence influences the path through the atmosphere and thus influences both the scattering and the absorption. These processes depend both on the wavelength of the radiation and on the type and quantity of absorbing and scattering media that the radiation penetrates before reaching the surface as Q_B. Because of selective absorption, the atmosphere absorbs far more radiation during the initial penetration than during subsequent multiple reflections between ground and sky.

The albedo of multiple-scattering media increases with decreasing angle of elevation of the incoming radiation. Measurements over snow under clear skies indicate a decrease in albedo by 8 to 20 percent as solar elevation increases from 10° to 24° (Petzold, 1977). While Q_B, depending on atmospheric conditions, retains more or less the original angle of incidence, the subsequent reflections between ground and sky constitute diffuse radiation. Diffuse radiation, when incident on a plane, has a large near-horizontal component of angles of incidence. This explains, at least in part, the commonly observed increases in snow surface albedo with increasing cloudiness. Thus, both the atmospheric albedo and the surface albedo for the initial penetration are different from the respective albedo values for the subsequent multiple reflections. In addition, the surface albedo for Q_B varies depending on its angular components.

The atmospheric albedo for Q_B may be defined as

$$A_o = Q_r \;/\; Q_o \tag{5}$$

where Q_r is the radiation reflected back to space by the atmosphere. The surface albedo for Q_B is

$$A_B = Q_{BG1} \;/\; Q_B, \tag{6}$$

the atmospheric albedo for subsequent reflections

$$A_{SM} = Q_{BSi} \;/\; Q_{BGi}, \tag{7}$$

and the surface albedo for diffuse radiation is

$$A_{GM} = Q_{BGi} \;/\; Q_{BSi}. \tag{8}$$

Using these definitions the numerical evaluation of Q_B and the subsequent additions, Q_M, proceeds as follows:

$$Q_B = (Q_o - Q_{ao})(1 - A_o) \tag{9}$$

where Q_{ao} is the radiation absorbed by the atmosphere in the initial penetration and $Q_{a1}, Q_{a2}, Q_{a3}...Q_{aN}$ represents atmospheric absorption in subsequent multiple reflections. If the calculation is performed for surface level, then

$$Q_{BG1} = Q_B \, A_B \tag{10}$$
$$Q_{BS1} = (Q_{BG1} - Q_{a1}) \, A_{SM} \tag{11}$$
$$Q_{BG2} = Q_{BS1} \, A_{GM} \tag{12}$$
$$Q_{BS2} = (Q_{BG2} - Q_{a2}) \, A_{SM} \tag{13}$$
$$Q_{BG3} = Q_{BG3} \, A_{GM} \tag{14}$$
$$Q_{BS3} = (Q_{BG3} - Q_{a3}) \, A_{SM} \tag{15}$$

⋮

etc.

until the values of Q_{BGi} and Q_{BSi} become negligible. In the following simulations it has been assumed that sky absorption amounts to 15 per cent of Q_o in the initial penetration and that atmospheric absorption in subsequent reflections is negligible. The sky albedo is regarded as independent of the upward or downward direction, i.e. after accounting for initial absorption, $A_o = A_{SM}$. The surface albedo is regarded as independent of direct or diffuse radiation, i.e. $A_B = A_{GM}$. These latter assumptions to some extent compensate for the assumption that atmospheric absorption in subsequent reflections is zero. The assumption that sky and surface conditions are spatially uniform is inherent in the model.

Influence of Multiple Reflections on the Observed $(Q + q)$

The influence of variations in sky and surface albedo was simulated for the possible range of each. The results are shown in Figure 1 in units of $(Q + q)/Q_o$. It is not correct, although common in the literature, to interpret this ratio as an indicator of the optical condition of the sky. This is because the ratio is influenced by both sky conditions and ground surface albedo. The true sky transmissivity is

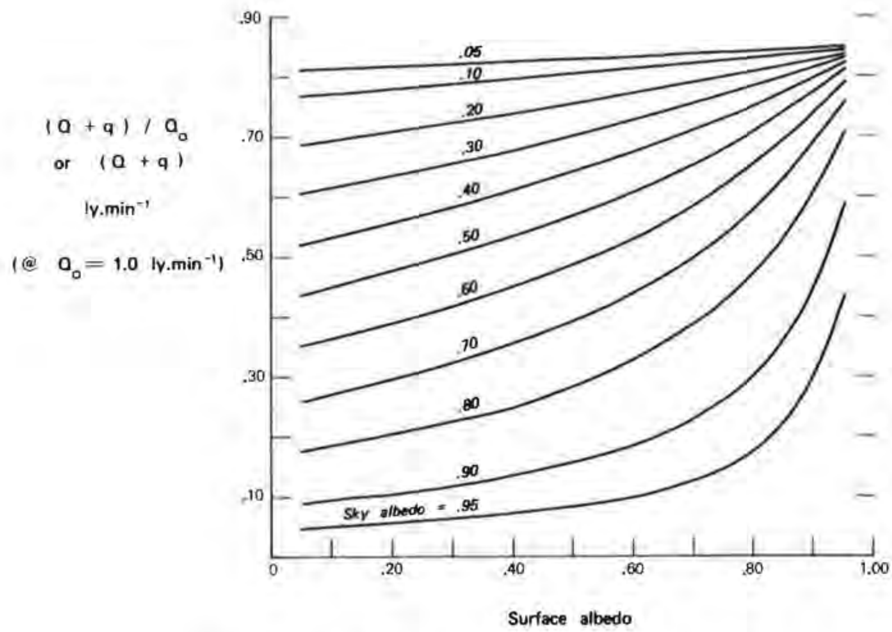

Fig. 1. Simulated $(Q+q)/Q_o$ for Different Surface and Sky Albedo.

obtained by this ratio only when the surface albedo is zero since the ratio then is reduced to Q_B/Q_o. If seasonal variations in $(Q + q)/Q_o$ are analyzed for stations in open terrain experiencing a seasonal snow cover, the ratio shows a marked increase when the snow cover is established in early winter and a decrease as the snow melts in spring.

The simulation indicates that multiple reflections between ground and sky significantly influence the measured $(Q + q)$ under all naturally occurring sky and ground conditions. It can increase the observed $(Q + q)$ to several times the transmitted radiation when both the sky albedo and the surface albedo are high. This explains the phenomenon noted by Holmgren and Weller (1973) that "the incoming solar radiation does not decrease very much when a cloud cover forms over an extensive snow field". The observed average solar radiation during six overcast days in April was only about 15 per cent less than the radiation income on clear days. Similarly, Ambach (1974) reports from a radiation study on the Greenland Ice cap that the ratio $(Q + q)/Q_o$ is reduced from about .82 to about .60 from conditions of clear sky to complete overcast. The average albedo during the survey which covered a summer season was .84. Had the surface albedo been .15 instead, then, according to the present model, the clear sky value of $(Q + q)/Q_o$ would have been .71 and the overcast value about .25. This is in reasonable agreement with observations at northern stations under respectively clear sky and overcast conditions in summer.

The simulation indicates the cause of the variations in brightness of an evenly overcast sky that can be observed above snow covered ground. The sky appears dark above forested areas and bright above open fields or snow covered lakes. In summer, a glacier can be spotted from a long distance because of the brighter sky above it. The variations in cloud brightness are particularly marked when an even cover of low cloud is present. If there is a high overcast, little or no variation in cloud brightness can be observed, unless the observation site is near the border between two large units of different surface albedo. A typical example is a large area of snow-covered fields bordering on a large coniferous forest. In this case, the sky gradually darkens over the forest. Albedo variations do not project well onto high overcast when the units are small because the reflected radiation is diffuse, both from ground and sky. Thus, with increasing cloud height, the spatial variations in Q_R and Q_M are reduced by spatial averaging towards mean values determined by the participating individual albedo units. The degree of averaging is determined by cloud height and by the size of the individual albedo units.

The influence of surface albedo on the spatial and temporal comparability of measurements of $(Q + q)$ can be illustrated if we imagine a station where the influence of the surrounding surface albedo changes as a result of changes in cloud height. Such a station, for example, might be an airport where the forest has been cleared in a roughly circular area of a radius of two kilometers. Let us suppose that the radiometer is located near the center of this clearing in an otherwise fairly undisturbed forest. Let the albedo of the forest be .1 in summer and .3 in winter and the albedo of the clearing .2 in summer and .7 in winter when snow covered. If we then introduce a low and a high overcast where the sky albedo is .8, we find that for a value of Q_o=1 ly min^{-1} in the case of low overcast when the clearing dominates the multiple reflections $(Q + q)$ in summer would be .20 ly min^{-1} and in winter it would be .39 ly min^{-1}. For high overcast when the surrounding forest dominates the multiple reflections, $(Q + q)$ in summer would be .18 ly min^{-1} and in winter they would be .22 ly min^{-1}, all under skies of identical optical properties and with the same Q_o. If we were to use the radiation measurements at the station under the assumption that 10 kilometers into the forest $(Q + q)$ is the same as that measured at the station, then the error due to this assumption would, under conditions as above, result in an over-estimate of .17 ly min^{-1} or 77 per cent in winter under low overcast. In summer, under otherwise identical conditions, the overestimate would be .02 ly min^{-1} or about 11 per cent of the actual $(Q + q)$ incident at the forest site. For an increasing height of the cloud cover the error due to the aforementioned assumption decreases so that for an overcast of high alto-stratus it is probably negligible for a clearing of this size.

Two stations experiencing similar cloud conditions but a consistent difference in surface albedo should experience a difference in the measured $(Q + q)$. The difference would be such that the station with the greater surface albedo also measures the greater amount of solar radiation. One example where the present author is familiar with the field conditions is a comparison between $(Q + q)$ measured simultaneously at Schefferville and at the Timmins 4 permafrost experimental site 20 km northwest of Schefferville (Petzold, 1974). The elevation of Schefferville is about 500 m and Timmins 4 is about 700 m A.S.L. The survey was undertaken during the snowmelt season in 1972. Throughout the snowmelt season the albedo is consistently higher at Timmins than at Schefferville. By the beginning of melt the general albedo of the snow-covered, largely treeless, Timmins area is around .70 while the Schefferville area with its tree cover probably has an average albedo of around .40. By the time the snow cover and the lake ice have melted around Schefferville the average albedo is less than .20. The albedo at Timmins is then still considerably higher because of the absence of trees and because parts of the terrain are still snow-covered (Granberg, 1972). On a large scale, the conditions at Schefferville extend eastwards for some 80 km across the Labrador Trough and the Timmins 4 conditions extend for an even longer distance westwards across the Canadian Shield. The border line is approximately halfway between the two stations.

Petzold's analysis of hourly averages over the melt season gave the regression equation

$$(Q + q)_{Tim} = 0.06 + 1.05\ (Q + q)_{Sch} \qquad (16)$$

in units of ly min^{-1}. The correlation coefficient is .96. Petzold concludes: "The consistency of this relation indicates a systematic difference in the order of 11% (at a value of $(Q + q)_{Sch} = 1.0$ ly min^{-1}) for every 600 feet in elevation" and argues that areas of the Churchill River basin with consistently higher elevations receive greater amounts of solar radiation due to the shallower atmosphere above. However, the observed difference during more or less clear sky conditions is a very large one to be explained on the basis of altitude alone. Nor have such, similarly attributable, differences been found elsewhere in the literature. The present model suggests that the observed difference is a real one but that it is mainly caused by the general difference in surface albedo.

The examples above indicate that multiple reflections have an influence on (Q + q) that in many applications ought not to be ignored.

Effects of Multiple Reflections on Radiant Absorption; Singular and Composite Surface Albedo

Many natural surfaces are composed of different materials which often differ considerably in individual albedo values. Because of diffuse reflection, the radiation reflected from a surface with albedos A_1, A_2,...A_n is uniform when it reaches cloud level if the individual units are small in relation to cloud height. The surface thus influences the multiple scattering as if it were homogeneous with an average albedo, A_G, which may be computed from

$$A_G = \sum_{i=1}^{N} d_i A_i \tag{17}$$

where $d_1 + d_2 + ...+d_n = 1.0$ and represent the decimal fraction of the total area occupied by each individual surface albedo. This average surface albedo is used in the simulation program to compute (Q + q). The average absorption by the surface, Q_{AG}, is then

$$Q_{AG} = (Q + q)_{AG} (1 - A_G). \tag{18}$$

The individual absorption by the different surfaces is computed by

$$Q_{Ai} = (Q + q)_{AG} (1-A_i). \tag{19}$$

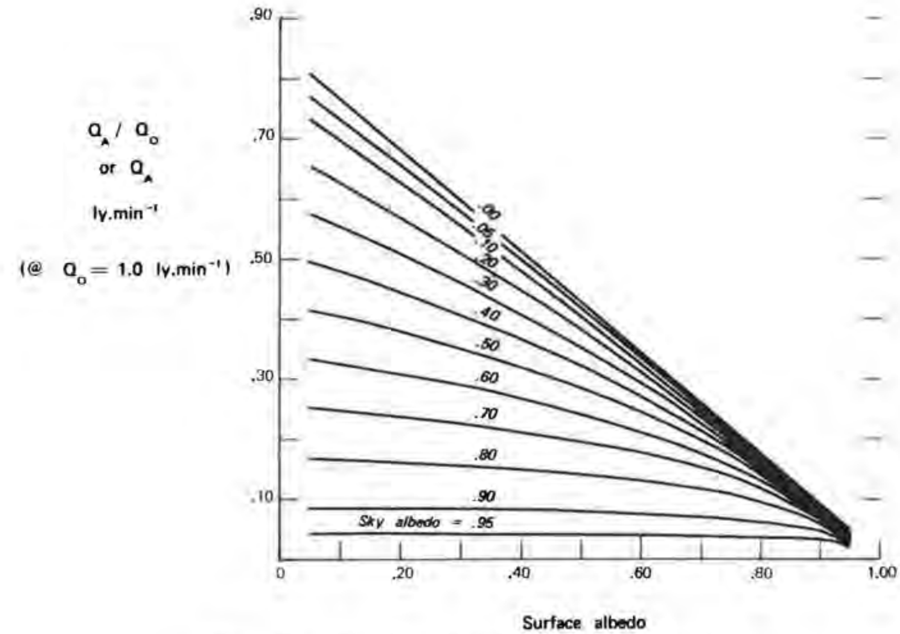

Fig. 2. Simulated Absorption Q_A/Q_o for Different Surface and Sky Albedo.

A simulation of the radiant absorption by the surface under different sky and surface conditions is shown in Figure 2, in units of Q_{AG}/Q_o. The figure shows that the radiant absorption in terms of the radiation available at the top of the atmosphere is a linear function of surface albedo only when the sky albedo is zero. When the sky albedo increases, the surface albedo becomes less important to the radiant absorption by the surface. Thus for a sky albedo of .8, the radiant absorption by a surface with an albedo of .7 is nearly 70 per cent of what a perfectly black surface would absorb under identical sky conditions. Similarly, when the surface albedo is high, sky conditions do not influence the radiant absorption very much. For a surface albedo of .85 such as that of a dry snow field, the absorption at a sky albedo of .8 is no less than 65 per cent of what is absorbed at a sky albedo of .2. The former sky albedo represents heavy overcast conditions and the latter, clear sky conditions. These results may be quite relevant in predictions regarding the stability of Arctic and Antarctic ice under varying cloud conditions.

When the surface is of composite albedo, variations in the composition have an influence on the radiant absorption by the individual components. This influence is not easily elucidated by measurement. Examples of natural situations of interest in this respect are the effects of variations in forest density and the effects of changes in albedo composition during snow melt when, gradually, the surface changes from complete snow cover to bare ground. The present model was used to simulate these situations.

In the case of snow melt, it was assumed that snow covered ground has an albedo of .7 and snow free ground an albedo of .2. The simulation is intended to represent a tundra surface with an evenly patchy distribution of snow and bare ground where the area occupied by bare ground gradually increases from 0 to 100 per cent. The assumed value of Q_o is 1.0 ly min^{-1}. The simulated absorption under different sky conditions is shown in Table One. For clear sky conditions the absorption per unit area by each of snow and bare ground by the end of melt is 89 per cent of the absorption at the start of melt. By contrast the absorption under heavy overcast is 53 per cent. This reduction in absorption is a result of the reduction in general surface albedo which causes a reduction in $(Q + q)/Q_o$. The average absorption by the ground surface thus increases but as a result of the decreasing percentage area occupied by snow of high albedo, the absorption per unit area of both snow and bare ground decreases. Thus, within the ground - sky system there is a transfer of radiation from surfaces of high albedo to surfaces of low albedo through the process of multiple reflections between ground and sky. This phenomenon can be quite important to many natural processes. Using Table One, but interpreting it in terms of coniferous forests of different densities, it can be seen that forest density through this mechanism influences the radiant absorption by trees. Perhaps this is an important factor influencing the spacing of trees in the open woodlands of the Labrador-Ungava peninsula (Hustich, 1954; Hare, 1959). Perhaps also the presence of a lichen mat of high albedo is essential to the survival of trees under the marginal conditions in the vicinity of the tree line in this area.

The transfer of radiation from surfaces of high albedo to surfaces of low albedo also operates in border zones between larger units of different albedo. Thus, a forest on the shore of a large snow covered lake in winter receives more radiation near the lake shore. Away from the lake $(Q + q)$ is gradually reduced towards a value determined by sky conditions and forest albedo. The same transfer phenomenon is also of importance to the energy balance of a glacier. If the glacier is of sufficient size and is surrounded by bare ground, then the radiant absorption increases towards the middle of the glacier. For the bare ground surrounding the glacier, radiant absorption is greatest at the edge of the glacier and declines with distance away from the glacier. Accordingly, radiation measurements used in mass and energy balance studies of glaciers are not easily correctly extrapolated over the glacier unless a fairly large number of radiometers are situated at different points on the glacier.

Conclusions

The present simulations indicate that $(Q + q)$ measured at a station is influenced by the albedo of the ground surface surrounding the station. This influence varies with sky conditions and surface albedo and is, in most cases, also variable with cloud height. The influence appears to be significant at all naturally occurring values of sky and surface albedo. Therefore, depending on the particular use, radiation data at any one station may not be strictly comparable through time. Nor, in the same sense, are data from two different stations strictly comparable. Fortunately, the error introduced by neglecting the effects of multiple reflections in work on temporal or spatial aspects of solar radiation is relatively small in the common range of surface albedo of less than about .3. However, when the overall albedo is high and when the spatial and/or temporal variations in albedo are great, such neglect can introduce serious errors. In such cases the influence of multiple reflections is sufficiently great to seriously affect the assumption of spatially uniform solar radiation even if the distance of extrapolation is short.

Multiple reflections within the ground - sky system cause a transfer of radiation from surfaces of high albedo to surfaces of lower albedo. Some of the effects predicted by the present model are:

1. Through snow melt, as the snow cover is gradually reduced, radiant absorption by both snow covered and snow free surfaces is reduced on a per unit area basis, when Q_o and sky conditions are kept constant.

2. As the density of a coniferous forest decreases, the radiant absorption by both trees and snow increases on a per unit area basis.

3. For a glacier surrounded by bare ground, radiant absorption increases towards the center of the glacier.

For the surrounding bare ground, radiant absorption is greatest near the edge and declines with distance away from the glacier.

The simulation model oversimplifies the complex phenomenon of multiple reflections between ground and sky and its use for numerical prediction would certainly require considerable refinement. However, comparisons with radiation studies available in the literature indicate that the simulations relatively well represent actual conditions. The present conclusions are therefore thought to be basically valid, although actual effects may be either more or less pronounced than the model indicates.

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TABLE ONE

Radiant Absorption by Snow and Bare Ground at Different Stages of Melt

Snow Fraction:	1.00	.80	.60	.40	.20	.00
Average Surface Albedo:	.70	.60	.50	.40	.30	.20

Computed Values of Q+q for Different Sky Albedo

Sky Albedo						
.2	.791	.773	.756	.739	.723	.708
.3	.753	.726	.700	.676	.654	.633
.4	.708	.671	.637	.607	.580	.554
.5	.654	.607	.567	.531	.500	.472
.6	.586	.531	.486	.447	.415	.386
.7	.500	.440	.392	.354	.323	.297
.8	.386	.327	.283	.250	.224	.202

Radiant Absorption for Different Sky Albedo

Sky Albedo	Snow	Bare	Snow	Bare	Snow	Bare	Snow	Bare	Snow	Bare	Snow	Bare*
.2	.237	.633	.232	.618	.227	.605	.222	.591	.217	.578	.212	.566
.3	.226	.602	.218	.581	.210	.560	.203	.541	.196	.523	.190	.506
.4	.212	.566	.201	.537	.191	.510	.182	.486	.174	.464	.166	.443
.5	.196	.523	.182	.486	.170	.454	.159	.425	.150	.400	.142	.378
.6	.176	.469	.159	.425	.146	.389	.134	.358	.125	.332	.116	.309
.7	.150	.400	.132	.352	.118	.314	.106	.283	.096	.258	.089	.238
.8	.116	.309	.098	.262	.085	.226	.075	.200	.067	.179	.061	.162

* Small areas of bare ground or snow patches covering less than 1% of total area.

AN INITIAL INVESTIGATION OF RADIATIVE EXCHANGE AROUND A TREE TRUNK SURROUNDED BY SNOW

by

John E. Lewis and Bhawan Singh*

Introduction

Doughnut shaped depressions around the trunks of trees and similar protuberances are commonly observed and characteristic features of a winter snow pack. These depressions have been variously referred to as "qáminiq" - an Eskimo word - (Pruitt, 1957; Lettau, 1966) and "melt holes" (Geiger, 1965). Geiger (1965) suggests that these melt holes are primarily due to radiative exchange processes between the snow pack and the tree trunks. Lettau (1966) on the other hand infers that these bowl shaped depressions are essentially produced by the turbulent action of the wind in the immediate vicinity of the tree trunk. In the present investigation, an attempt is made to assess the contribution of radiative exchange processes in the formation of these depressions. This is executed by examining the fluxes of the energy balance for a hardwood tree trunk in a mid-winter snowpack.

Methodology

It is the suspicion of the authors that both the geometry of insolation for an upright tree trunk and radiative exchange processes between the snow pack and the tree trunk are the major contributing mechanisms for the formation of these melt holes. During the low winter sun period, the vertical tree trunk presents an enhanced surface in terms of the angle of incidence of the sun's rays, thereby increasing the

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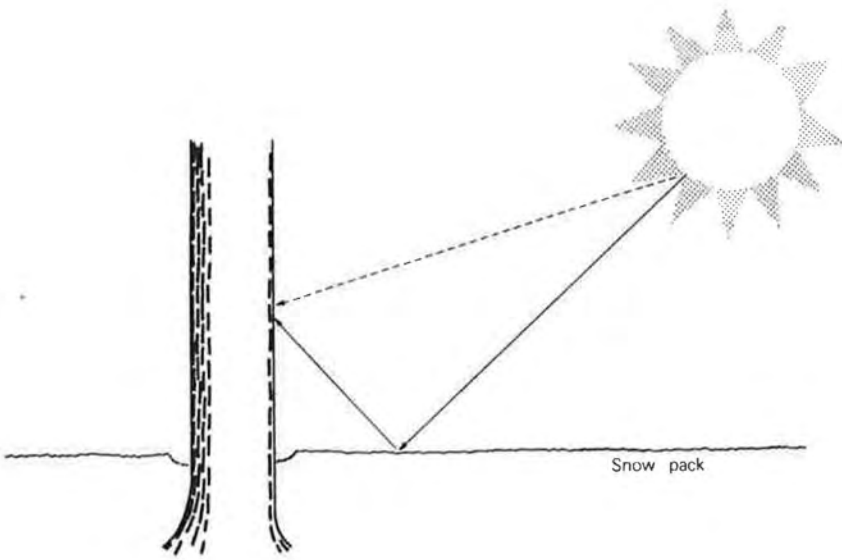


Fig. 1. Tree Trunk in Relation to Snow Pack.

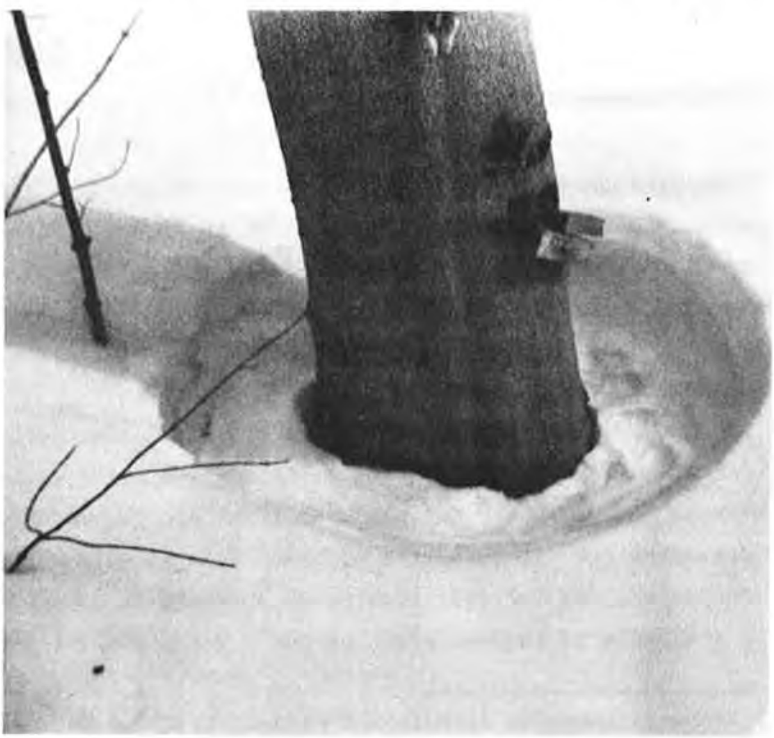


Fig. 2. Depression around a Tree Trunk.

intensity of insolation over that of a horizontal plane. In addition, the position of the tree trunk in relation to the snow pack (see Fig. 1) enhances solar radiation receipt on the surface of the trunk by means of the forward scatter process. The radiation balance then of the tree trunk may be written as

$$Q^*_t = \{(Q_v + q_v) + (Qh + qh)\ \alpha s\ \}\ (1 - \alpha t) + L{\downarrow}k + L{\downarrow}s - L{\uparrow}t \quad (1)$$

where Q^*_t is net radiation of a vertical tree trunk, Q_v and q_v are respectively the direct and diffuse solar radiation arriving at the tree trunk, Qh and qh are respectively the direct and diffuse solar radiation incident on the snow pack, αs and αt are the surface albedos of the snow pack and the tree trunk respectively, $L{\downarrow}k$ and $L{\downarrow}s$ are the long wave radiant fluxes incident on the tree trunk from the sky and the snow pack respectively, and $L{\uparrow}t$ is the long wave emission from the tree trunk towards sky and snow pack. Similarly, the radiation balance of the snowpack in the immediate vicinity of the tree trunk may be written as

$$Q^*_s = \{(Qh + qh) + (Qv + qv)\ \alpha t\ \}\ (1 - \alpha s) + L{\downarrow}k + L{\downarrow}t - L{\uparrow}s \quad (2)$$

where Q^*_s is net radiation of the snowpack and all other terms are as defined for Equation (1).

In terms of the present experiment, the critical energy transfer whereby the doughnut shaped depressions are formed are envisaged as being in the following sequence: (a) the enhanced radiation receipt on an upright tree trunk; (b) the conduction of the absorbed portion of that energy through the trunk in the direction and to the level of the snow pack; (c) the subsequent long wave emission from the tree trunk; and (d) ultimately the absorption of this energy by the snow pack, especially in the immediate vicinity of the tree trunk. This greatly enhanced receipt and absorption of solar radiant energy increases surface temperatures and thus intensifies long wave emission from the tree trunk. The component of this energy flux directed to the snow pack produces melt, particularly in the vicinity of the tree trunk, since snow absorbs radiant energy strongly in the long wave band. That these processes are operative, are suggested by the shape of the depressions in that they seem to be more developed on the sunnier south-facing sides of the tree trunk (Fig. 2). Also the fact that the depressions seemed to grow in

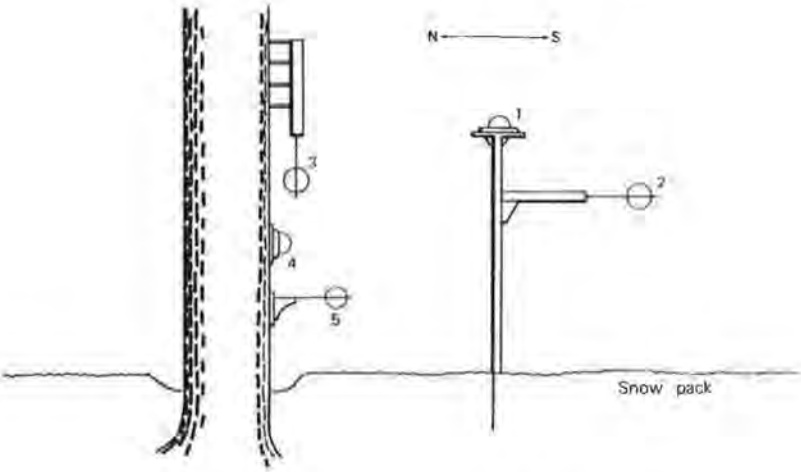


Fig. 3. Instrumentation Used in Experiment.

1. Global radiation on a horizontal surface (Q+q)h; 2. Net Radiation (horizontal) over snowpack – Q^*_h; 3. Global radiation (vertical) along tree-trunk (Q+q)v; 4. Net radiation (vertical) over tree-trunk Q^*_v; 5. Net radiation over the depression Q^*_d;

* not shown are the solarimeter to measure the albedos and radiation thermometer (PRT-5).

dimensions during the early spring period would also strongly suggest the importance of radiative exchange factors.

Site and Instrumentation

Field measurements for the experiment were conducted at Mont St. Hilaire, Quebec. The trunk (ca 0.5 m diameter) and immediate vicinity of sugar maple tree on a gently sloping south facing slope of one of the more exposed hills (East Hill) was selected for measurements. The forest is essentially of the mixed hardwood variety, with sugar maple (Acer saccharum March) and beech (Fagus grandifolia Ehrh) species being predominant. This type of vegetative cover has obvious advantages for a study of this nature in view of the almost unimpeded penetration of solar radiation to the level of the snow pack. Field measurements were done on the 16th and 21st of February, 1977, when the snow pack was fully mature. The depth of the snow pack at the measurement site was about 1 metre. Both days were characterized by mainly sunny skies during the period of observation. Figure 3 summarizes the relative placement of instruments and the different measurements taken. Both global (Lintronic dome solarimeter; calibration 25.96 mv/ly) and net (CSIRO net radiometer; calibration 55.8mv/ly) radiation were measured on a horizontal plane over an exposed and relatively unobscured portion of the snow pack in

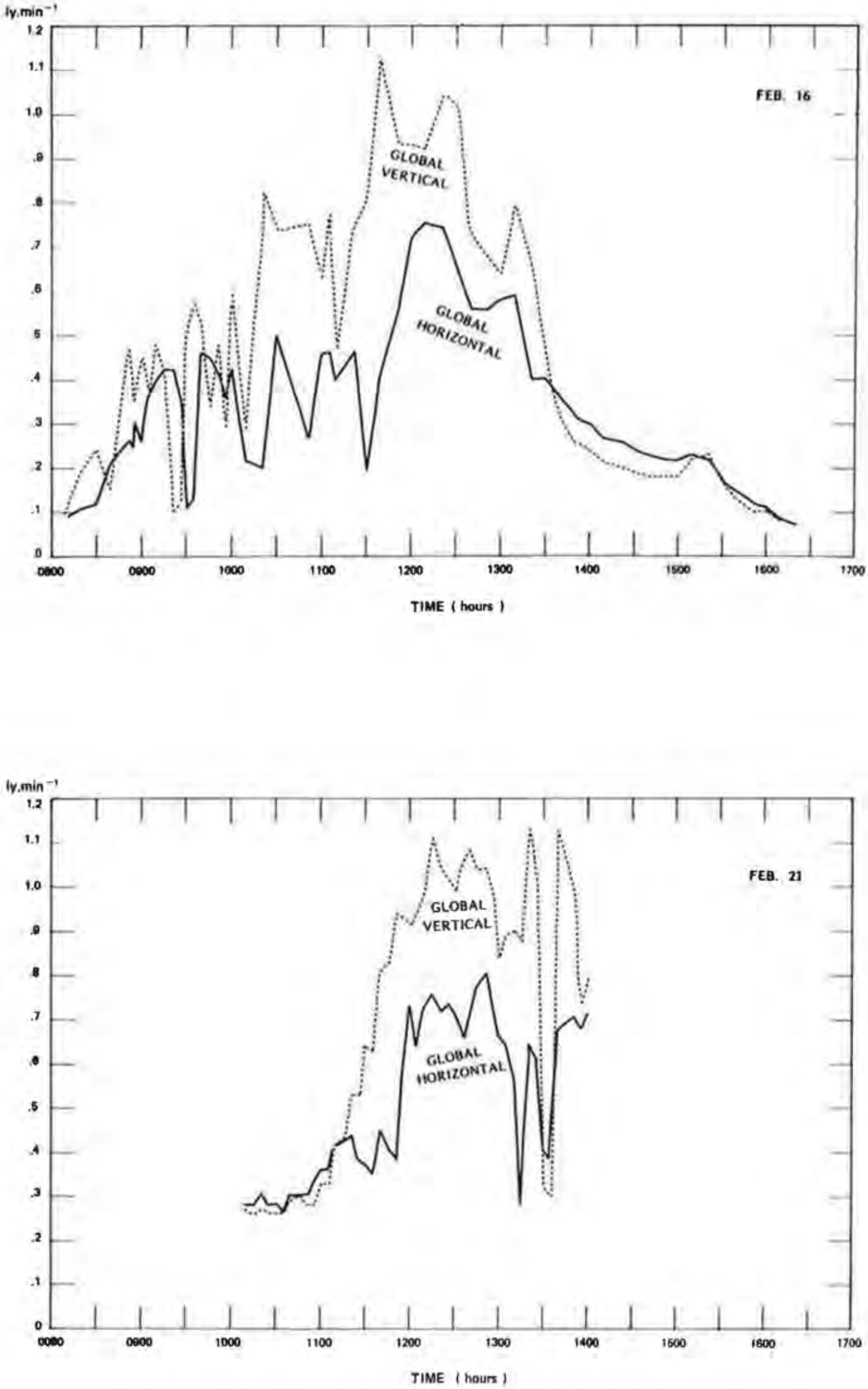


Fig. 4. Global Radiation on Tree Trunk (vertical) and Horizontal Surface.

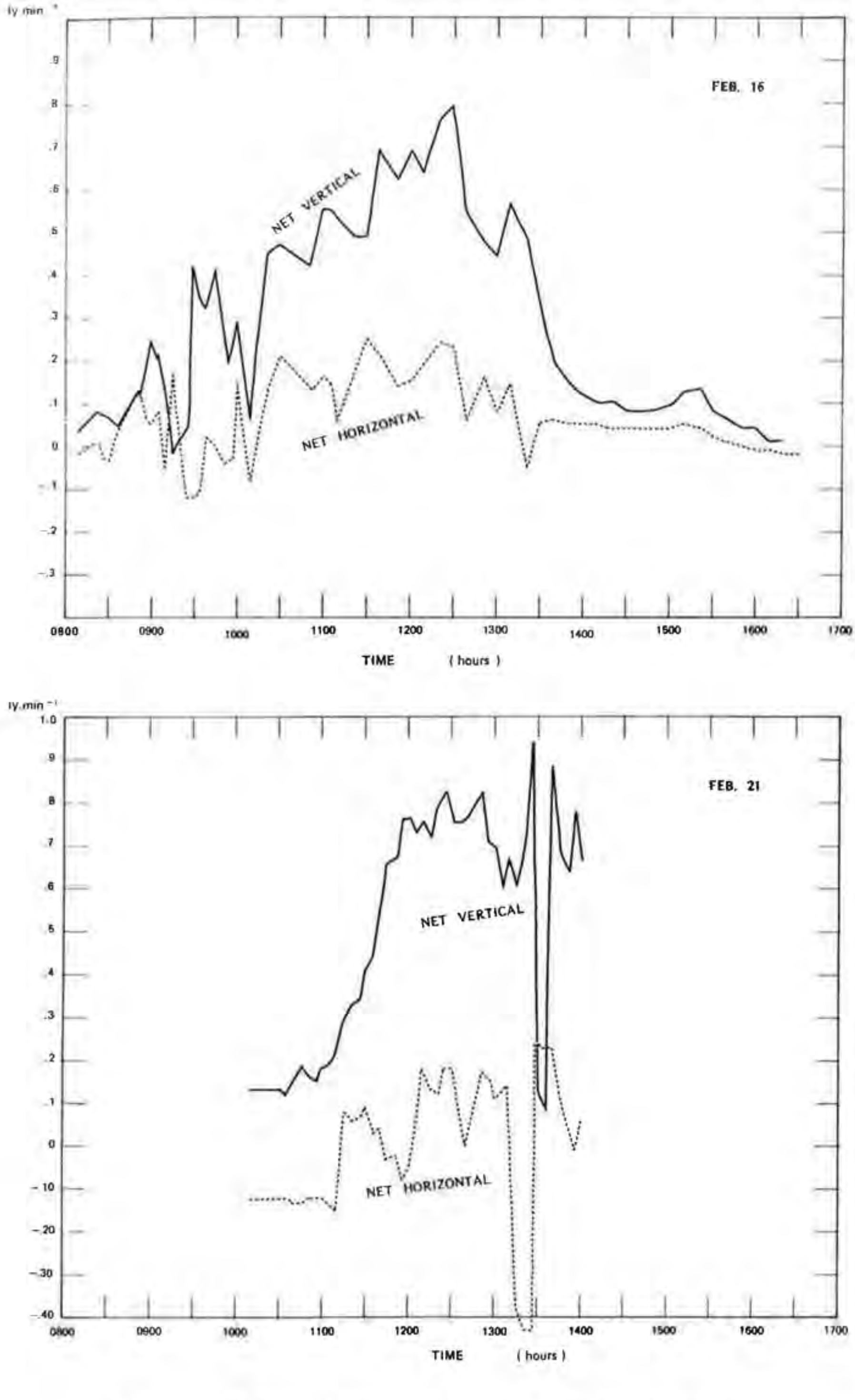


Fig. 5. Net Radiation on Tree Trunk (vertical) and Horizontal Surface.

the immediate vicinity of the instrumented tree. Global (Lintronic dome solarimeter; calibration 27.16 mv/ly) and net (Swissteco, Type S-1 net radiatiometer; calibration 27.23 mv/ly) radiation were also measured on a vertical plane parallel to the tree trunk. In this latter case, the net radiometer was so positioned as to allow the sensing element facing away from the sun to "see" only the trunk of the tree. As a means of getting a feel for comparable values, net radiation (Micromet net radiometer; calibration 3.0 mv/ly) was also measured over the south facing side of the depression, on a horizontal plane. Albedo measurements (down facing Lintronic dome solarimeter; calibration 24.97 mv/ly) were also collected for both the snow pack and the tree trunk. Since mounting of the instruments created some disturbance of the snow pack, albedo measurements were done for both disturbed and undisturbed portions of the pack for the first set of observations. In an attempt to devise values of the terrestrial long wave fluxes from both the snow pack and the tree trunk, surface radiant temperatures were measured by means of a PRT-5 radiation thermometer (Barnes Engineering Company). All measurements, except those for surface albedo and surface radiative temperatures, were recorded continuously on a digital recorder, with signal outputs being printed at 5-minute intervals. Because of the time involved in getting to and from the measurement site, albedo and radiant temperature measurements were done every hour on the hour.

Discussion of Results

Tables One through Four * and Figures 4 through 6 summarize the results of the data collected and analyzed. It is readily apparent from Figure 4 that global radiation receipt on the upright tree trunk is much greater than that on a horizontal plane, which corresponds to the approximate level of the snow pack. During peak radiative periods (ca 1200 hrs) insolation on the tree trunk is about 0.2 to 0.3 ly min^{-1} higher than on the snow pack. It would appear that this difference could be accounted for by forward scatter from the adjacent snow pack, together with the difference in the angles of incidence for an upright, as opposed to a horizontal, instrument exposure. Note that on certain occasions there exist differences between both the magnitude and direction of both fluxes, this discrepancy being due to shading of the instruments relative to one another by adjacent trees. Similar differences are noticeable for net radiation receipt (Fig. 5) on the tree trunk as opposed to the

* at end of article.

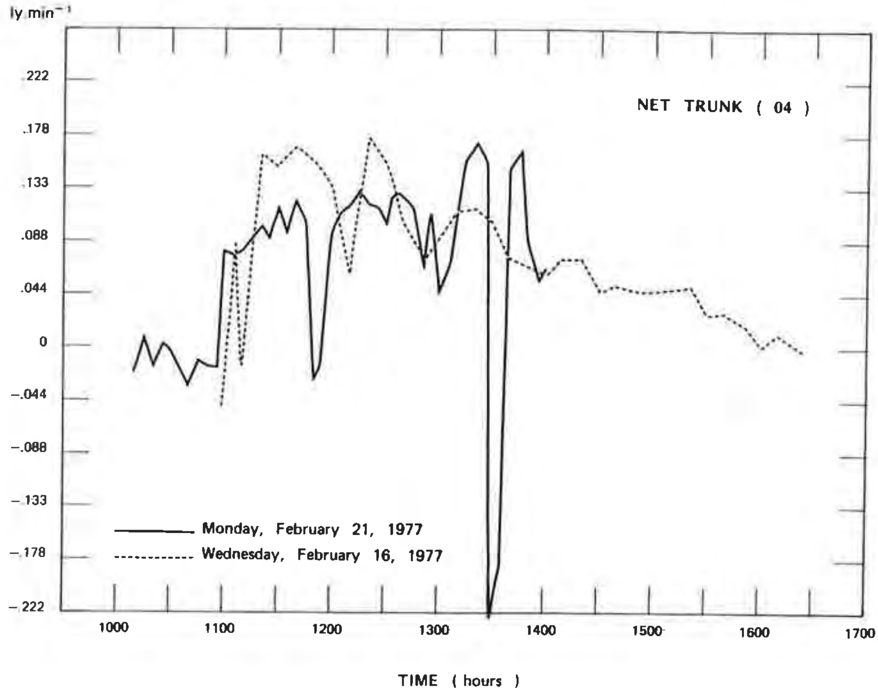


Fig. 6. Net Radiation over Depression.

snow pack. In this instance however, during peak radiative receipt (ca 1200 hrs) values of net radiation on the tree trunk are much higher than those of the snow pack, i.e. by about 0.5 to 0.6 ly min^{-1}; this added difference can be accounted for mainly by the relatively higher albedo values of the snow pack along with the increased absorption of solar radiation on the vertical facing tree trunk (see Tables One and Two). The results of the miniature net radiometer positioned just above the snow depression which surrounds the tree are given in Figure 6. It is difficult to assess the meaning of the lower net radiation values when compared to the horizontal net radiation over the snow pack proper. One might speculate that the lower values are a result of increased radiation receipt as viewed by the lower hemisphere of the radiometer. The instrument "looks at" a cavity type structure which could have the effect of concentrating radiative exchange.

In an attempt to explain the different radiative exchange processes in terms of Equations (1) and (2), so as to highlight the effect of the long wave exchange between the tree trunk and the snow pack, the different components of both equations are measured or estimated separately. These values are summarized in Tables One through Four. Albedo values for the snow pack (αs) were taken both for undisturbed and disturbed portions of the snow pack with the mean value derived from these two measurements at the specified observation times. Five centimeters of snow fell between February 16 and 21 which produced the need for measuring only undisturbed snow albedo values on the second date. The long wave fluxes from the snow pack and the tree trunk were calculated from measured radiant temperature values using the Stephen-Boltzman relationship which can be written as

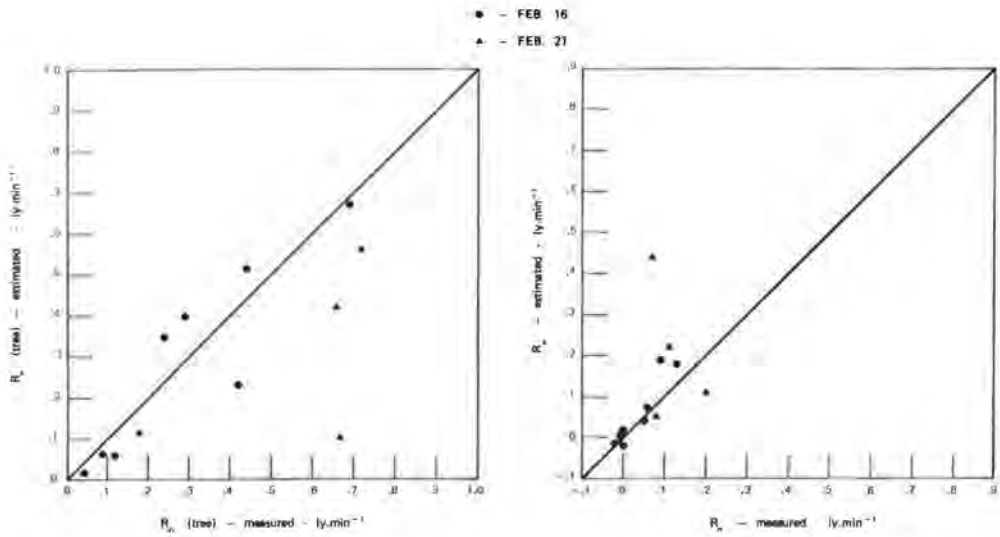
$$L\uparrow = \varepsilon \, \sigma \, T^4 \quad \text{ly min}^{-1} \tag{3}$$

where $L\uparrow$ is the long wave emission from the tree trunk ($L\uparrow t$) or snow pack ($L\uparrow s$), ε is surface emissivity, σ is the Stephen-Boltzman constant (8.132×10^{-11} ly min^{-1} $^{o}K^{-4}$) and T is surface radiant temperature (^{o}K). Surface emissivity for the tree trunk was taken to be 0.96, a value which corresponds to that of tree bark for similar type vegetation (Fuchs and Tanner, 1966). Also surface temperatures of the south facing section of the tree trunk were utilized, although surface temperature differences compared with the north side as much as 10^{o}C can exist. Surface emissivity of the snow pack on the other hand was taken to be 0.89, since this value corresponds to that for compacted snow as given by Sellers (1965, p. 41). This value also lies in the range of values given elsewhere (Baumgartner, 1957). Moreover, the values of emissivity utilized appear to be realistic since, as shown by Bijleveld (1977, p. 23), a variation in emissivity by as much as 10 per cent, for apparent sky temperatures near the freezing point, will produce a difference between real and radiative temperatures of less than 2^{o}C.

The long wave flux from sky to ground ($L\downarrow k$) was estimated by means of the following expression:

$$L\downarrow k = (208 + 6\,T_a)/697 \quad \text{ly min}^{-1} \tag{4}$$

where T_a is in ^{o}C. The above formula is attributable to Monteith (1973) and is applicable to clear sky conditions. The assumption of the existence of clear skies for both measurement days may be somewhat strained in the sense that isolated thin cloud patches drifted by on both days. Also the average air temperatures for both days, which did not vary appreciably, were utilized.



(a) Using Equation (1) (b) Using Equation (2)

Fig. 7. Comparison of Calculated and Observed Net Radiation.

In calculating the net energy flux for the upright tree trunk, in terms of Equation (1), both the fluxes of the long wave emission from the snow pack ($L{\downarrow}s$) and the sky ($L{\downarrow}k$) were halved, as suggested by Kondratyev (1969) in order to derive a more appropriate view factor to what the tree trunk "sees". Similarly in computing the net flux incident on the snow pack, in accordance with Equation (2), both the fluxes from the sky ($L{\downarrow}k$) and the tree trunk ($L{\uparrow}t$) were halved in an attempt to achieve consistent results. The estimated values of the net radiant flux incident upon the tree trunk (Q^*_t), calculated according to Equation (1) when compared with the measured values of this same flux (Fig. 7a), show that the values are similar. Apart from the errors that may arise from the instruments, and from assumptions pertaining to emissivities and view factors, the most serious shortcoming here seems to be related to the extent of cloud cover when estimating sky long wave radiation. This is very apparent in Figure 7a for February 21, when the presence of a fractional cloud cover (ca .02) caused a consistent underestimation for the estimated as opposed to the measured flux.

Figure 7b compares the net radiation flux estimated by means of Equation (2) with the values measured over the snow pack (Q^*_s). Again the results are very similar. Apart from the discrepencies arising from the same mechanisms as described with respect to Figure 7a, another atypical condition arises, namely that the estimated flux on occasions seem to be very much higher than the measured fluxes. This condition is probably due to relative shading effects on the instruments by adjacent trees.

Summary and Recommendations

From the foregoing analysis, it is evident that radiative exchanges, particularly the long wave emission from the tree trunk to the snow pack, are the contributory factors for the development of the doughnut shaped depressions over the winter snow pack of a hardwood forest. From field observations it is also apparent that turbulent wind conditions produced by the protrusion of the tree trunk above the snow has some effect in the formation of these depressions. In addition, the establishment of a snow pack allows for the tree trunk to become a veritable conductor of stored soil heat. Radiation penetration through the snow pack to the trunk may also be important. The isolation of these causative mechanisms and their measurements would require more sophisticated and elaborate instrumentation than was possible in the present experiment.

The present experiment procedure is, indeed, deficient in several respects. The geometry of insolation on the different surfaces, especially with respect to the view factor must certainly be improved. In addition, some technique that considers shading effects on instruments relative to one another by adjacent trees is very desirable; and the values of surface emissivities and long wave sky radiation need to be measured or estimated with greater precision.

A project of this nature would appear to have relevance for water balance studies in forested snow-covered areas. A certain, though small, volume of the snow pack around each tree when removed can significantly reduce the snow available for melt in the spring, especially if most of the removed snow is evaporated before the spring thaw sets in.

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TABLE ONE

Summary of Radiant Temperature, Long-wave Flux and Albedo Values
(February 10, 1977)

Time (EST)	Trunk Radiant Temp °C	*L↑t ly min^{-1}	Snow Sfc T. °C	**L↑s ly min^{-1}	Albedo Tree %	Mean Albedo
09:30	-12.0	0.36	-17.0	0.32	0.48	0.95
10:05	- 9.0	0.38	-16.0	0.32	0.48	0.95
11:15	- 4.0	0.41	-13.0	0.33	0.44	0.99
12:00	1.0	0.44	-10.0	0.35	0.46	0.84
13:00	- 1.0	0.43	-11.5	0.34	0.38	0.77
14:00	- 3.0	0.41	-12.5	0.33	0.60	0.84
15:00	- 5.0	0.40	-13.5	0.33	0.49	0.87
16:00	- 9.0	0.38	-15.0	0.32	0.46	0.82
		*ε = 0.96		**ε = 0.89		

ε = emissivity, * = average albedo from disturbed and undisturbed site.

TABLE TWO

Summary of Radiant Temperature, Long-wave Flux and Albedo Values
(February 21, 1977)

Time (EST)	Trunk Radiant Temp °C		L↑t ly min^{-1}		Snow Sfc Temp °C	L↑s ly min^{-1}	Albedo Tree %	Albedo Snow %
	S.Facing	N.Facing	South	North				
11:00	-2.5	-3.0	0.42	0.41	-7.0	0.37	0.58	0.89
12:15	6.5	-0.5	0.48	0.40	-4.5	0.38	0.60	0.93
13:10	8.5	-1.0	0.49	0.43	-5.5	0.38	0.81	0.96
14:00	7.0	-1.0	0.48	0.43	-6.0	0.37	0.53	0.63
						ε = .89		

ε = emissivity

TABLE THREE

Radiant Components for Tree Trunk

Time (EST)	Qv + qv (A)	(Qh+qh) αs (B)	A+B(1−αt)	L↓s	L↓k	L↑t	Q^*_t (Est)	Q^*_t (Meas)
FEB. 16								
09:30	0.51	0.10	0.32	0.16	0.11	0.36	0.23	0.42
10:05	0.59	0.40	0.51	0.16	0.11	0.38	0.40	0.29
11:15	0.47	0.39	0.48	0.17	0.11	0.41	0.35	0.24
12:00	0.93	0.59	0.82	0.18	0.11	0.44	0.67	0.69
13:00	0.64	0.43	0.66	0.17	0.11	0.43	0.51	0.44
14:00	0.24	0.24	0.19	0.17	0.11	0.41	0.06	0.12
15:00	0.18	0.17	0.18	0.17	0.11	0.40	0.06	0.09
16:00	0.10	0.09	0.10	0.16	0.11	0.38	0.01	0.04
FEB. 21								
11:00	0.33	0.32	0.27	0.19	0.13	0.42	0.11	0.18
12:15	1.11	0.70	0.72	0.19	0.13	0.48	0.56	0.72
13:10	0.90	0.53	0.27	0.19	0.13	0.49	0.10	0.67
14:00	0.79	0.45	0.58	0.19	0.13	0.48	0.42	0.66

All values in ly min^{-1}.

TABLE FOUR

Radiant Components of Snow Pack in the Vicinity of Tree Trunk

Time (EST)	Qh + qh (C)	(Qv+qv) αt (D)	C+D(1−αs)	L↓k	L↓t	L↑s	Q^*_s (Est)	Q^*_s (Meas)
FEB. 16								
09:30	0.24	0.02	0.11	0.18	0.32	0.32	0.02	0.00
10:05	0.42	0.28	0.04	0.11	0.19	0.32	0.01	0.00
11:15	0.40	0.21	0.02	0.11	0.21	0.33	0.00	−0.02
12:00	0.72	0.43	0.21	0.11	0.22	0.35	0.18	0.13
13:00	0.58	0.24	0.21	0.11	0.22	0.34	0.19	0.09
14:00	0.30	0.14	0.09	0.11	0.21	0.33	0.07	0.06
15:00	0.22	0.09	0.07	0.11	0.20	0.33	0.04	0.05
16:00	0.11	0.05	0.04	0.11	0.19	0.32	0.01	0.00
FEB. 21								
11:00	0.36	0.19	0.06	0.26	0.21	0.37	0.05	0.08
12:15	0.75	0.67	0.10	0.26	0.24	0.38	0.11	0.20
13:10	0.55	0.73	0.05	0.26	0.50	0.38	0.22	0.11
14:00	0.71	0.42	0.42	0.26	0.24	0.37	0.44	0.07

All values in ly min^{-1}.

EXAMEN INITIAL DES ECHANGES RADIATIFS AUTOUR DU TRONC D'UN ARBRE PENDANT L'HIVER

Résumé préparé par Bhawan Singh

Les troncs en forme de beigne (qáminiq) trouvés dans la neige autour des troncs d'arbres sont attribués aux échanges radiatifs entre la neige et les troncs et aussi à la turbulence éolienne produite par les troncs. Un programme des travaux sur le terrain a été effectué à Mont St-Hilaire au Québec en vue d'étudier le premier effet. Deux journées au mois de février, 1977, alors que le ciel était clair ont été choisies pour mesurer: a) le rayonnement solaire horizontal sur la neige, b) le rayonnement solaire vertical sur le tronc d'un arbre, c) l'albedo des deux, neige et tronc, d) le rayonnement net horizontal sur la neige, e) le rayonnement net vertical sur ce même tronc, f) la température rayonnante du ciel et g) la température rayonnante de la surface de la neige et du tronc d'arbre.

Brièvement, les résultats de la recherche démontrent à la fois que l'arrivée du rayonnement solaire sur le tronc, augmentée, pendant l'hiver, par son orientation verticale et le rayonnement solaire réfléchi par la neige en avant sur ce même tronc augmentent la quantité d'énergie donc aussi absorbée sur la surface des troncs. Cette quantité d'énergie calorifique accumulée par le tronc et donc l'augmentation de la température rayonnante du tronc permet une émission améliorée de rayonnement d'ondes longues vers la neige environnante. Puisque la neige absorbe fortement le rayonnement d'ondes longues, on peut facilement croire que des processus d'échanges radiatifs contribuent signicativement à la fonte de la neige autour des troncs d'arbres.

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NEWS AND COMMENTS

The following report is contributed by Ben Garnier of McGill University who was "Climotologist in Orbit" for the Friends of Climatology during the 1977-78 session.

"My activities as orbiting climatologist were confined to two months; February and March, 1978. I had intended to start earlier. This was, however, frustrated in a not inappropriate manner by the weather. The initial take-off to London and Windsor planned for Wednesday, January 18, was prevented by one of the three or four heavy snowstorms which hit southern Ontario and Quebec, and northern New York state around then. So the start of orbiting was put off for two weeks.

The second attempt, on Wednesday, February 1, was successful. A morning flight took me from Dorval airport to London where Bob Packer met me and drove me by the "country route" to Western University. This was my first visit to Western and I was glad to be able to see the campus with its mixture of fairly old and more modern architecture. The talk of the town was the heavy snowstorm which had paralysed the region some time earlier; one of those once in a hundred year events so that I was unable to appreciate how different this part of Ontario is supposed to appear in winter when compared with Montreal or Quebec. This of course made me feel very much at home, as did the kind and generous welcome of Bob Packer and his colleagues, and also the students. I gave two talks at Western: one was on my work in the evaluation and mapping of surface variations of global and net radiation, and the other was on the results of some of the research I had done into the surface heating of Barbados, with particular reference to the surface heating of east-facing slopes. These two talks were the two officially scheduled for the orbiting climatologist this year. Of the two, the former has been the most in demand. At Western, however, it appears to have been the latter which occasioned the most interest, especially in various follow-up letters I have had from one or two students.

After an afternoon of talks and pleasant entertainment at the Faculty Club, Bob Packer drove me to the station where I caught the evening train to Windsor. A restful night in the Holiday Inn followed, and in the morning Marie Sanderson came to collect me to take me to the Windsor campus. This visit was my first to Windsor since the inaugural meeting of Friends of Climatology in 1968. So it was very pleasant to return and to be able to reflect on the progress of our group as well as to meet staff and students. The morning was spent in discussion with students and also with John Jacobs, and then, after lunch, I gave a presentation to an advanced undergraduate group, with some visitors, of the radiation evaluation and mapping talk. This was followed by an hour of discussion, which included some non-student members who were working in the fields of architecture, engineering, and solar energy. This provided a good practical flavour to the discussion, and as usual under such circumstances provided a scientist with the healthy challenge of "what is the point of it all?" Unfortunately, it was necessary to cut the discussion short to make a hurried journey to the airport and back to Montreal.

The second venture into orbit took place in order to visit the Atmospheric Environment Service in Toronto. My inclinations as an earthbound geographer coming to the fore on this occasion, I kept my orbit as close to earth as possible by taking the train to Toronto on the Thursday evening to be in time for the seminar scheduled for 11 a.m. on Friday, February 10. This took place in the comfort of the spacious auditorium at AES and for me brought back memories of the fine seminar series arranged for the Centenary of the Canadian Meteorological Service. Whether my own presentation on radiation matched the standard of that occasion I doubt, but I was glad to have the opportunity to discuss some of my ideas with an adult audience of professional meteorologists. The visit also provided me with the opportunity of meeting a number of old friends, Bruce Finlay, Gord MacKay, and David Phillips among others, the latter being responsible for the arrangements for the meeting. I was glad, also, to get some fresh viewpoints on the potential applications of the evaluation and mapping techniques for global and net radiation, and also to update my familiarity with various research and other activities in the climatological sections of AES.

Ten days later I was back in Toronto again, this time to visit three campuses of the University of Toronto. On this occasion the subjects of talks and discussion were changed in order to accommodate an interest in physiological climatology. Since my days in Nigeria I have been interested in this topic more as a hobby than as a line of research, and on the strength of this interest I was asked to talk about the principles of physiological climatology both at Erindale College and the St. George campus of the University. Both of these talks were given to second and third year undergraduate classes. On the third day of the visit I went to Scarborough College. Here the discussion emphasised the more practical aspects of my work on the radiation balance of slopes by applying it principally to the field of solar energy, both in the area of solar energy intensity and the principles of a rational climatology for solar energy. Christopher Sparrow had been responsible for the main organisation of the visit, with the particular arrangements for Erindale and the St. George campus being made by Scott Munro and Geza Szeicz respectively. The three days provided a most pleasant and instructive visit, which gave me an opportunity of meeting many members of staff who had before been mainly names to me. It also enabled a considerable exchange of ideas both in the field of climatology itself and also in relation to some of the general problems facing Canadian universities at the present time.

During the month of March two visits into orbit were made. The first retained the tradition of an earthbound geographer by taking the train from Montreal to Kingston on Tuesday March 7. Harry McCaughey had expected I would take the early train, rather than the mid-morning rapido, and so we just had time to get from the station (CN being on time) to the University for a presentation to staff and students on the heating effects arising from the position of Barbados in the trade wind zone. Dinner that evening took place in an interesting restaurant which had previously been the town fire station. The next morning gave me a chance to see over the department before discussing radiation on slopes with a third-year undergraduate class. Lunch at the Faculty Club was followed by an afternoon discussion with Maurice Yeates, the department chairman. This was particularly interesting in view of the relatively recent introduction of doctoral work in geography at Queens which provided some ideas of how our own setup at McGill might be improved, especially in relation to the Ph.D comprehensive examinations. CN trains, however, do not wait for academic discussion, and so I had reluctantly to leave to return to the station to catch the evening turbo back to Montreal.

The last venture into orbit took place on the last day of March. It was to McMaster University. In a sense it was the most genuinely "orbital" of all the visits in that I left my apartment in Montreal only half-an-hour earlier than usual, and was back in the evening at my usual time. In the interval instead of going the $4\frac{1}{2}$ miles each way from where I live to the department at McGill, I had been the 400 miles each way to Hamilton and put in a "normal" day's work. The latter included the pleasure of meeting with John Davies and Wayne Rouse, having an excellent lunch with them, other staff, and graduate students in the Faculty Club, and seeing the facilities and equipment of the climatology section of a department which is so well known in the field. My presentation on this occasion was to a group of graduate students together with some senior undergraduates and also staff members. I found it a particularly profitable occasion in which I was able to review work in the area of radiation on slopes and its applications to various problems, and to listen to the comment, criticisms, and suggestions of several persons now engaged in expanding the original work."

Two recent visitors to the Department of Geography at McGill University were of particular interest to climatologists. The visitors were Dr. Tom Wigley of Climate Research Unit, University of East Anglia, and Dr. Michael Glantz of NCAR, Boulder, Colorado.

Dr. Wigley was on campus only a few hours during which time he gave a stimulating talk on the work of the Climate Research Unit of the University of East Anglia. Particular attention is paid by this unit to the question of climatic change and variability. In this work great attention is being paid to historical record: indeed, part of the climatic research team comprises an expert in the reading and deciphering of manuscripts, and economic and social historians.

Michael Glantz was able to spend three days in Montreal. During this time he talked to undergraduate, graduate and staff seminars and formal class groups. The discussion formed a series based on the work Dr. Glantz is doing on various aspects of drought, with particular reference to West Africa. The main thrust of his discussion was that climate is not the villain: climate is behaving as it should behave, with "to be expected" ups and downs as part of the normal global circulation. Much of the "drought" and its effects, therefore, must be related to social, economic, and political factors and attitudes and their consequences in the face of normal climatic patterns and variability.

There are several theses titles of interest to climatologists in a recent list of doctoral and masters theses published in the Professional Geographer, Vol. XXX, No. 1, February, 1978. The list was prepared by Robert H. Stoddard of the University of Nebraska.

A. Doctoral Theses.

Granger, Orman E. "The Evapotranspiration Climatonomy of the Lake Ontario Drainage Basin", University of Toronto, 1974.

Kay, Paul Allen. "Post-Glacial History of Vegetation and Climate in the Forest-Tundra Transition Zone, Dubawnt Lake Region, Northwest Territories, Canada", University of Wisconsin-Madison, 1976.

Ryerson, Charles C. "Models for Calculating Daily Changes in Soil Frost Depth in the Midwestern United States", Southern Illinois University - Carbondale, 1977.

Wax, Charles Larry. "An Analysis of the Relationships between Water Level Fluctuations and Climate, Coastal Louisiana", Louisiana State University, 1977.

B. Masters Theses.

Ahmad, Ismail. "A Water Budget Approach to the Prediction of Caliche Depths in Soils of the Western United States", Ohio University, 1976.

Blanchais, Auguste. "Contribution à l'étude de l'influence d'une ville sur le rayonnement solaire: exemple de Montréal", McGill University, 1976.

Burt, James. "Human Thermal Comfort in the United States", University of California, Los Angeles, 1976.

Caiazza, R. "Atmospheric Nutrient Loadings in Central Alberta", University of Alberta, 1976.

Clapp. Roger. "Infiltration in Relation to Rainfall Intensity: An Investigation of an Empirical Equation Using Simulated Data", University of Virginia, 1977.

Danielewicz, Zbigniew W. "Some Characteristics of Large Scale Winter Chinnooks in Southern Alberta", University of Calgary, 1977.

Greene, Gordon M. "Testing an Urban Climate Stimulator", University of Michigan, 1977.

Harrell, Haywood S. "The Effect of Heat Waves on Mortality Rates in Central and Eastern North Carolina: The July, 1906 Example", University of North Carolina, Chapel Hill, 1977.

Knox, Craig S. "Analysis of Wind Flow Patterns and Calm Air Patterns in the San Francisco Bay Area", Oregon State University, 1977.

Malan, John J. "Vertical Temperature Profile: Indexes for Expressing Differences between Microclimatic Areas", Northern Illinois University, 1977.

Payant, Michel. "A Study of Evapotranspiration over Muskeg in a Sub-Arctic Environment", McGill University, 1977.

Philipp, Kurt R. "The Water Budget as a Predictor of the Growth of White Pine", University of Delaware, 1977.

Saulesleja, A. "Evaporation from Lake Wabamum, Alberta", University of Alberta, 1976.

Scholefield, P.R. "Map Types and Related Weather over the Mackenzie Valley", University of Alberta, 1976.

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Symptomatic of increasing interest in climatic, as opposed to meteorological, problems is the development of the World Climate Programme sponsored by the World Meteorological Organisation. The WMO Bulletin for January 1978 (Vol. XXVII, No. 1) reports on a World Climate Conference held at WMO headquarters from 13 to 23 February, 1978. The conference had as its aims "to review knowledge of climatic change and variability, due to both natural causes and human activities; to asses possible future climatic changes and variability and their implications for human activities; to prepare for a possible subsequent conference at ministerial level, and to define possible courses of action for consideration at such a conference".

Readers of the Climatological Bulletin will be interested in two forthcoming conferences both of which will be held in August.

(a) The Solar Energy Society of Canada is organising a conference on "Renewable Alternatives". It will be held at the University of Western Ontario from August 20 to 24.

(b) The World Meteorological Organization is sponsoring a symposium on forest meteorology to be held in Ottawa, Canada, 21-25 August, 1978. The symposium is being hosted jointly by the Canadian Forestry Service and the Atmospheric Environment Service of Canada. The purpose of the meeting is to bring together scientists from all over the world who have a common interest in the scientific problems of forest meteorology as well as the applications of meteorology to forestry.

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