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Net Radiation During Clear Weather in the Snow-Free Season for Various Types of Surfaces, Poste-de-la-Baleine (Great Whale), Québec

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Article abstract

During the snow-free seasons 1972-1975, point fluxes of net radiation (Q*) and incoming solar radiation (K↓) were measured in clear weather for different surfaces near Poste-de-la-Baleine (Great Whale), Québec. The relationship between Q* and K↓ is described for each type of surface in terms of the simple ratio Q*/K↓. 100% and the linear egression curve, to enable estimates of net radiation to be made from the more available measured or calculated K↓.

The results suggest that the use of portable instruments for relatively short periods of carefully controlled field observations offers an inexpensive method of predicting net radiation in the less accessible north, if the measurements are stratified according to weather and surface conditions. A comparison of the regression curves permits a simple quantitative estimate of the potential differences in the net energy at the surface, resulting from projected changes to the terrain with northern development. The curves in this present article refer to clear weather. Although it is relatively rare on this coast, it is believed to have an importance in the energy climate and ecology quite beyond its limited frequency.

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NET RADIATION DURING CLEAR WEATHER IN THE SNOW-FREE SEASON FOR VARIOUS TYPES OF SURFACE, POSTE-DE-LA-BALEINE (GREAT WHALE), QUEBEC

The relationship between net radiation and incoming solar radiation.

by

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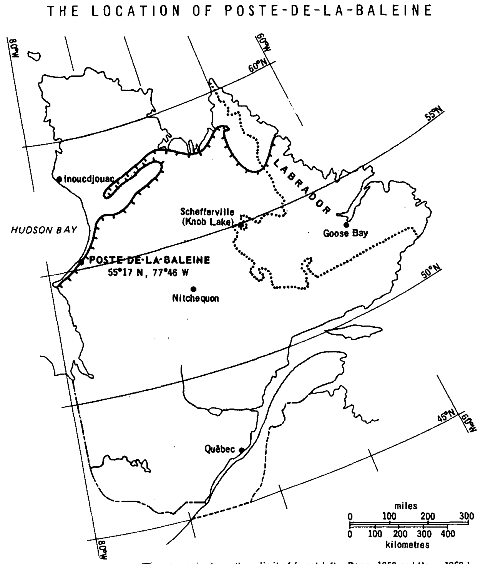
INTRODUCTION

As part of the multidisciplinary research project « Hudsonie », undertaken by the Centre d'Études nordiques to study a variety of environmental factors along the east coast of Hudson Bay, series of measurements of surface energy exchange components were made during the snow-free seasons of 1970, 1972, 1973, 1974 and 1975, near Poste-de-la-Baleine, Québec. One of the aims of the energy exchange programme was to try to determine characteristic regional values associated with the different weather conditions and surface types. In two previous articles (Wilson and MacFarlane, 1971, Wilson, 1972), net radiation and its relationship to global solar radiation were discussed for a variety of surfaces under cloudy, damp conditions, together with the possibility of obtaining frequencies of such energy situations through the use of standard surface hourly weather data ; with cloudy, damp conditions, spatial variation was found to be practically eliminated in this coastal area. The present study deals with net radiation for similar surfaces under the rarer, but potentially important dry, clear conditions. The work is confined to daylight hours.

Figure 1

THE LOCATION OF POSTE-DE-LA-BALEINE



WEATHER

Poste-de-ia-Baleine (55° 17N) is situated at the coast (figure 1) on the northen shore of the estuary of the Grande rivière de la Baleine, and

Figure 2a *Location of the study area.*

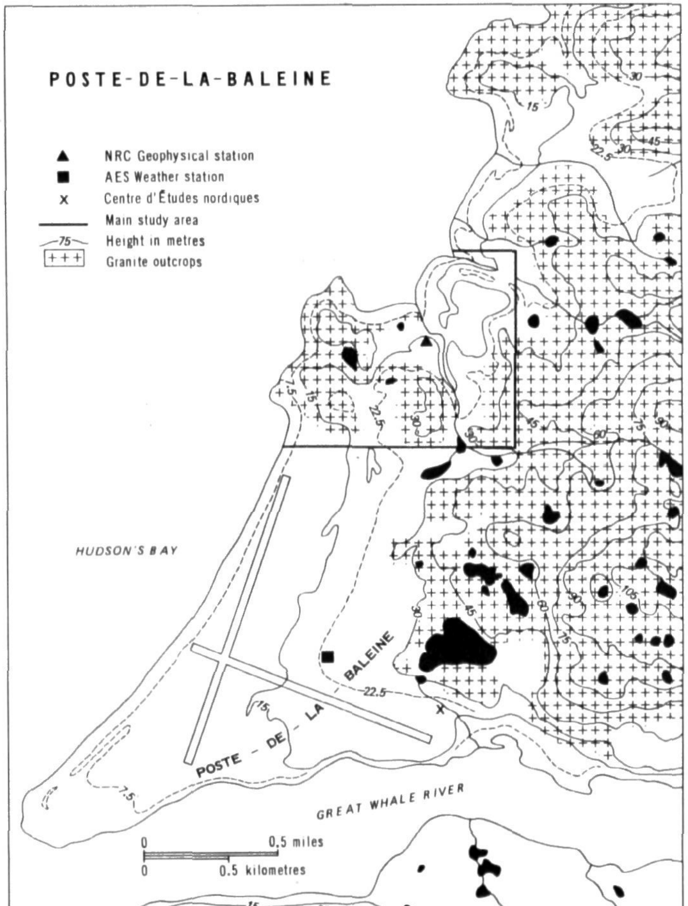
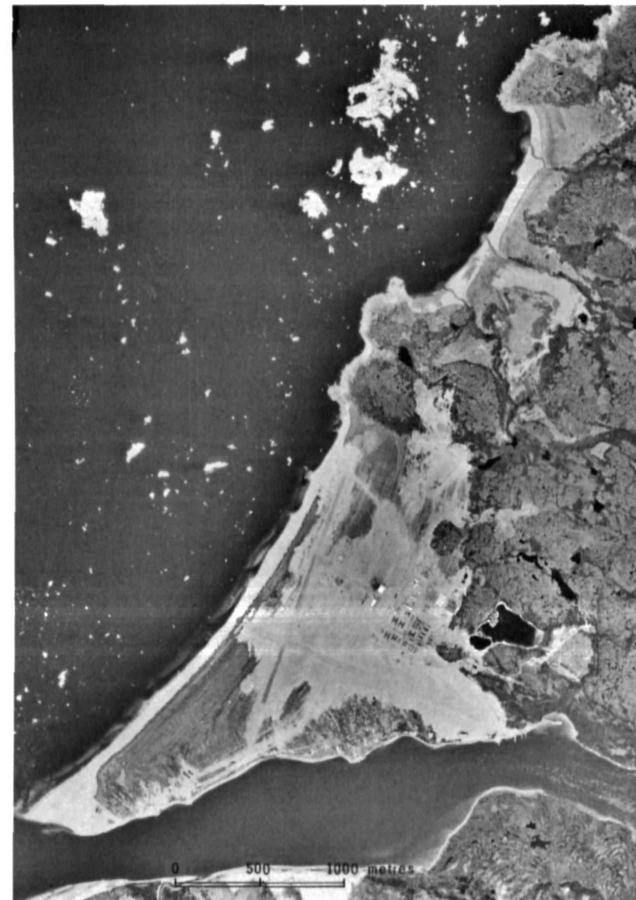


Figure 2b *Aerial view of Poste-de-la-Baleine.*
PHOTO 1231-77, Ministère des Terres et Forêts, Québec.



near the northern limit of tree growth (Payette, 1975). The ice in Hudson Bay can persist well into July and the offshore waters remain relatively cold until the early autumn (cf. Danielson, 1969). As a result, the climate [1] includes many aspects usually associated with Arctic coasts, and there are individual years when the mean daily temperature of the warmest month does not reach 10°C.

A succession of depressions from the SW and W dominates the weather bringing much cloud and rain at this season; these periods are separated by days with clearer anticyclonic conditions. During the late spring and summer, the surface westerlies in the warm sector of the depressions undergo considerable cooling in the lowest layers as they cross the Bay. Further aggravated by the topography, this results in cold, damp, foggy weather on the coast, with a layer of heavy low cloud and frequent drizzle. At this time of year, the clearer sky conditions accompanying higher pressure can be quickly obliterated by a local drift of air from the sea or a well-developed sea breeze, which shrouds the coast in low-level cloud or mist. Later, towards mid-September, the cold northwesterly winds are increasingly modified by the now relatively warm waters of the Bay, and unstable weather marked by the development of heavy cumulus cloud is characteristic. As these cells reach the coast, visibility frequently drops to near zero in a rain or snow squall, to be followed by a brief period of exceptional clarity, with shafts of brilliant sunlight intensified by reflection from the cloud sides.

This brief account points to the preponderance of cloud at the coast. In 1969, only 9% of the hourly observations at Poste-de-la-Baleine during the daylight period showed clear sky or 1/10 cloud cover, and 8 to 9%, clear sky or cirrus of quantity-opacity <0.5 (Caron, 1972). On the other hand, overcast (9/10 — 10/10 cloud cover) was reported on 60% of the daylight hours, and in one half of these cases consisted of low-level cloud or fog (Plamondon-Bouchard, 1975).

TERRAIN

The study area is shown in Figures 2a, b. A number of sites are illustrated in Figure 3. In clear weather, the differences in net radiation, from one type of surface to another, would be expected to be greatest.

The coastal region and its immediate hinterland form part of the Precambrian shield. The present-day relief bears witness to the last glacial advance in which continental ice completely covered the area, and to the subsequent marine invasion (Tyrell Sea), from which the land is still slowly

[1] A more detailed summary of the climate of Poste-de-la-Baleine is contained in an earlier publication (Wilson, 1968).

emerging. Two major types of terrain can be distinguished: the granite-gneiss outcrops and the coastal terraces (raised beach ridges) [2].

The granite-gneiss outcrops

The low granitic plateau rises in steps towards the interior ; at 4 to 5 km inland, hill crests reach 150 to 235 m. high. In general the hills are aligned E-W or ESE-WNW. Glacial action directed from the east has given a characteristic asymmetry to the surface features, the steeper and more rugged slopes more often facing W or WNW. During the marine phase, the finer materials were washed out of the moraines, leaving the rock surfaces strewn with fields of boulders and isolated blocks. Near the coast, this granitic base forms a series of low platforms supporting numerous rock pools and small lakes.

Payette (1973) has described in detail the sequence of soils which have developed on this uniform bedrock in relation to topography and drainage, as well as the vegetation cover associated with each. The main surface types include :

1. — the convex surface forms, including the rock outcrops, boulder fields, isolated blocks and more recent detrital material, mostly encrusted with lichens. The associated lithosols are very thin and discontinuous with no apparent organic horizon ;

2. — the remaining granitic areas, where lithic regosols have formed. The surface type varies according to slope and drainage. Sites range from those excessively drained or exposed to the wind to poorly drained depressions. With increasing dampness, the organic horizon generally becomes deeper (from representative values of about 7 cm to 15 cm); the colour varies from very dark brown to black when wet to very dark grey when dry. Lichens and ground shrubs dominate the drier sites, together with sedges and dwarf willow where it becomes less dry or less exposed. On mesic sites, such as the edges of small lakes or the lowest parts of well-drained land, vegetation consists of mosses, sedges and other herbs, ground shrubs, dwarf willow and spruce. In the wet depressions on the granite platforms and on some valley floors, the cover is made up of sedges, cotton grass and other low herbs, ground shrubs, willow and mosses. Small thin sphagnum-sedge peat bogs occur on the granite, of average depth less than 0.5 m.

Coastal terraces – raised beach ridges

The amount of post-glacial isostatic uplift in this area appears to be over 250 m. Along the coast and in the valleys, the finer glacial materials

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[2] Detailed accounts of the geomorphology are given by CAILLEUX and HAMELIN (1969-1970), PORTMANN (1971, 1974), HILLAIRE-MARCEL and DE BOUTRAY (1975) and ROCHETTE (1970), and form the basis of this summary.

have reappeared as large accumulations of marine sands, marking phases in the continuing retreat of the sea. These deposits have been in part re-worked by river action and marine currents. The result is a series of spectacular terraces along the estuary of the Grande rivière de la Baleine, and of raised beach ridges on the north shore, both at the mouth of the river and between outcropping granite promontories along the coast.

On the terraces at the south shore of the river mouth and along the raised beach ridges to the north, the strong winds on this coast have created a series of active parabolic dunes. Those along the beach ridges occur a few hundred metres from the shore and are aligned to form a succession of arcs apparently moving along the coast in a resultant NE or NNE direction. In places, dune walls rise as high as 6 to 15 m above large adjoining deflation surfaces of up to 3 hectares in area, where marine gravels and pebbles of the raised beach are exposed, as well as occasional bedrock. Downwind, blown sand forms a veneer on the surface and accumulates in greater depth where higher vegetation and topography permit, frequently choking the small consequent streams which drain down from the plateau to the Bay. These streams cut small, narrow gullies and terraces as they cross the beach ridge deposits. Along the coast, the bedrock appears only sporadically through the covering of sand.

The soil profiles associated with this sandy material and the related vegetation cover are influenced locally by the degree of disturbance caused by wind action, and by local drainage conditions (cf. Payette, 1973 ; Payette and Gauthier 1972). The main surface types include :

1. — The lowest raised beach ridges (6-10m) just above the present shore zone, forming predominantly lyme-grass prairie (*Elymus arenarius* L.) with an increasing proportion of low grasses, other herbs and lichens towards the interior. The well-drained sandy soil is a coarse-grain, pale (wet) to very pale brown orthic regosol, with little development of an organic horizon. Sand outcrops sporadically, especially towards the shore zone, where the pioneer *Arenaria peploides* L. forms discrete round cushions fixing the sand ;

2. — The older, higher beach ridges (10-20m), with vegetation consisting mainly of lichens, with a few prostrate plants, occasional white spruce, and some colonies of crowberry, sedge and other low herbs. The well-drained, loosely-compacted, medium-grain sandy soils are typically degraded, dystric brunisols, of medium (wet) to very pale brown (dry). The dark grey (wet) to brown (dry) organic layer is mixed with and often overlain by the sand. However, this is the area of active dune building described above, and in the deflation zones the soil profile has usually been removed, while downwind it has become buried under blown sand. The dunes themselves, of coarse-grained sand, are colonised by Elymus wherever it can get a hold. Where eolian forms have been stabilized, the vegetation tends towards open lichen woodland ;

Figure 3 *Aspects of the different surfaces sampled.*

a. *Sand*

b. *Elymus arenarius*

c. *White spruce or lichen floor (back, right) birch and willow*

d. *Marsh*

e. *Rock ponds*

f. *Vegetation of granite outcrop*

3. — The gullies, where the rivers cut back into the terraces, and the zones of contact between the sandy material and the granite, sites which are frequently less well-drained or poorly drained. On slopes from 0 to 3°, orthic gleyed regosols have developed, the profiles differing according to the level and fluctuation of the water table. Where the water table is below the surface during most of the growing season, the dominant vegetation is willow, alder and birch, with sedges and grasses and in some places spruce. The well-developed organic horizon is black (wet) to very dark brown (dry). Where the soil becomes completely waterlogged, peaty gleys and bog intergrade with organic soils (sphagno-fibrisols). In the coastal area, the marsh surface consists of wet hummocks of sphagnum with dense tall coarse grass (*Calamagrostis canadensis* agg.), sedges and low willow, separated by narrow channels, puddles and larger pools of open water. White spruce and dense willow are associated with the edges of the marsh and occur occasionnally on the hummocks.

NET RADIATION : CLEAR WEATHER

Net radiation, Q^*, the net flux at the surface of total downward and upward radiation, conveniently integrates a number of highly variable components.

$$Q^* = (K\downarrow + L\downarrow) - (K\uparrow + L\uparrow), \qquad (1)$$

where $K\downarrow$ = downward direct and diffuse solar radiation,

$L\downarrow$ = downward atmospheric long-wave radiation,

$K\uparrow$ = upward solar radiation reflected by the surface.

$L\uparrow$ = upward long-wave terrestrial radiation

In clear weather, solar altitude, length of day and local topography largely determine the total radiant energy ($K\downarrow + L\downarrow$) received at the surface. However, when the sky is *apparently* clear, significant differences may occur in the downward radiation owing to the presence of a very thin cirrus layer, or a cirrus « haze » difficult to observe from the ground, or to changes in the quantity and vertical distribution of precipitable water or aerosols [3]. At Poste-de-la-Baleine there are a number of factors which tend to accentuate such fluctuations :

1. — local oscillations in the position of a jet stream overhead with variable development and dissipation of cirrus ;

2. — modification of the atmospheric temperature and humidity profiles in the lowest 100m or so over the coastal region during local cold air

[3] Considering the location of Poste-de-la-Baleine, the season and the local scale of the study, the effects of carbon di-oxide and ozone are assumed to be conservative.

advection from the Bay, as in the case of a sea breeze. At times an almost invisible low-level veil is present ;

3. — strong dessicating winds from the ESE to S, which lift the sand particles along the exposed coastal terraces ;

4. — occasional smoke pollution from forest fires – for example, in mid-July 1974 from fires burning in Northern Ontario. To what extent urban-industrial pollution from regions to the south affects Poste-de-la-Baleine is not known. There are however frequent contrails over and following the coast, as the zone has become an international air lane.

For any given radiation input, variations in outgoing total radiation ($K\uparrow + L\uparrow$) depend on the reflective and thermal properties of the different surfaces and the angle of incidence of the sun's rays.

Short-wave reflection coefficients ($K\uparrow / K\downarrow .100\%$) measured during clear weather in June over a variety of surfaces are given in Table 1. The values are considered representative for the daylight period. However, considerable variation can occur.

1. — The coefficients are dependent on the angle of incidence, the values usually increasing with decreasing solar altitude. Rouse's measurements of daily range for the west coast of Hudson Bay are included in the table.

2. — The reflectivity decreases with increasing surface wetness. Ångström (1925) described the coefficient as lowering by a third when a dry high grass became wet after rain (from 31–33% to 22%), and by about one half in the case of black humus (14 to 8%) and sand (18 to 9%). Recently, Idso *et al* (1975) reported a linear relationship between the reflection coefficient (normalized for angle of incidence) and the soil water content of the thin surface layer (<0.2cm) of a drying, bare loam soil : the coefficient ranged from 16% with volumetric water content of 0.19 to 26% at 0.06. Good correlations were also found with the average soil water content up to depths of 10cm. The sensitivity of the reflection coefficient to soil moisture content is essentially limited to vegetation – free soils (Aase and Idso, 1975).

3. — In the case of higher vegetation such as bushes or tall grass, the reflectivity also varies according to the degree of penetration, the nature of the substratum and the exposure of soil or water surfaces.

4. — Certain changes within the growing season are related to the stage in development of the vegetation cover, to the changes in colour and water content of the vegetative matter, and to the drying out of the surface after the late spring thaw.

Table 1

Poste-de-la-Baleine (55° 17N) : Clear-weather reflection coefficients (per cent), June 1975. Values representative for the day.

(Ground-based measurements using a Dirmhirn pyranometer, at 1.5 m, mounted to allow inversion)

Dry Sites (dry surface)	*Poste-de-la-Baleine*	*Values from other authors*	*Daily range*
Wind-blown sand surfaces	29	33	31 – 39 (Rouse)
Dry Lichens, mainly *Cladonia alpestris, C. mitis,* with sand cracks	21	22	18 – 27 (Rouse)
Crowberry (Empetrum nigrum L.), some lichen on sand	19		
Small white spruce, needles dry, standing on a carpet of lichens and crowberry	18		
Granite surface, smooth, lighter in colour	16		
Granite surface, darker, partially encrusted with black lichens	15	12 – 15	(Ångström)
Low birch bushes in early leaf stage, leaf cover not complete, exposing Juniper, small brown branches and some ground litter on sand	15		
Birch (as above), without substratum of Juniper, ground cover of dead branches, brown leaf litter and dried grass, on sand	14		
Wet Sites			
Edge of marsh; mosses, crowberry, blueberry, lichens, spongy carpet, saturated below, but surface not wet	18		
Black peat exposed in marsh, saturated, some water at surface. Tall, coarse, dry, brown grass (*Calamagrostis canadensis*), with new green shoots. Some disturbance by motor cycles and skidoos	14		
Black/brown peat, saturated but no water lying on surface. Vegetation churned in by motor cycles and skidoos	11 – 12		
Small rock pool water clear ~ 15 cm deep, sand and some brown litter at bottom, a little grass growing in the water	10		
Fringe of sedge meadow, shallow layer of surface water amid a growth of sedge		16	(Davies)
Sphagnum-sedge bog		16	(Berglund and Mace)
Lowland swamp		10	7 – 16 (Rouse)
Lake		7	3 – 15 (Rouse)
Baltic Sea, near shore, surface slightly disturbed (winds 3-6 m sec^{-1})			4 – 47 (Ångström)

Rouse (1973), West coast of Hudson Bay, 56°N; Davies (1962), Schefferville, 54° 48N;
Berglund and Mace (1972), Minnesota, 47° 31N. Ångström (1925), Sweeden 59° 23N.
(All values are from ground-based pyranometers in clear weather [4], mid-summer).

[4] For reasons of homogeneity, Cailleux's (1975) photometer measurements for surfaces at Poste-de-la-Baleine in cloudy weather have not been included.

5. — The pollution of the bare sand in the settlement and near the runways by vehicles and pedestrian traffic has reduced its reflectivity in those areas. Where the motorcycles and skidoos cross the marsh along the coast, churning in the vegetation, there has also been a decline.

In the long-wave range of the spectrum, the reflectivity is believed to be between 5 and 10% for many natural surfaces in the snow-free season, though may be higher in the case of dry sand (cf. Sellers, 1965). Assuming that these surfaces behave very nearly as black bodies, the long-wave emission, $L\uparrow$, is a direct function of surface temperature. For any given energy input it varies according to the specific heat and thermal conductivity of the surface material, or complex of materials, and to the height, density and structure of the vegetation cover. In general, both the specific heat and thermal conductivity increase when the surface material is wet.

In clear daylight hours during the growing season, variations in the net long-wave flux ($L\downarrow - L\uparrow = L^*$), in the reflected radiation $K\uparrow$, as well as in the total incoming solar radiation $K\downarrow$ (fluctuations both in the total and in the proportion of diffuse to direct), are generally small relative to $K\downarrow$ itself. They do however incorporate into the net radiation measurements, at any point in time, the radiative characteristics of local or regional weather (including advection) and local surface conditions. It is thus hazardous to extrapolate from such measurements beyond the locality or season studied.

It would appear that there is a degree of compensation in the interaction of these fluctuations, because the daytime ratio $Q^*/K\uparrow$ in clear weather remains relatively stable for a given locality and time of year, according to the nature of the surface. Linear regression of net radiation on total incoming solar radiation is already well-established as a useful tool for the prediction of the total energy available at the surface from the more available measurements or estimated values of $K\downarrow$. In this study an attempt has been made to establish a set of regression equations for the various types of surface along this coastal zone, in clear weather ; they are based on samples of point fluxes of $K\downarrow$ and Q^* using portable instruments.

MEASUREMENTS AND ANALYSIS

Total solar radiation (0.3 to 3.0 microns) was measured with a Dirmhirn Star pyranometer. Its design and performance have been described by Dirmhirn (1958) and Robinson (1966). Although this instrument was designed to allow equally sensitive measurements of about 96% of the incident radiation to within 10 to 15° of its plane, a laboratory check [5] on

[5] Calibration of the instruments and recorders was carried out by the National Radiation Laboratory of the Canadian Atmospheric Environment Service, and we wish to thank Mr. Ronald Latimer.

our two pyranometers showed the need for correction factors, which were applied ; accurate time checks were available at the nearby NRC Geophysical station. No measurements were taken when the sun's altitude was below 24° (i.e. when $K\downarrow$ was less than about 350 Wm^{-2}). Net radiation (0.3 to 60 microns) was measured with a Sauberer-Dirmhirn radiometer. The Kahlsico meter has two channels, but switching is required so that strictly simultaneous measurements of incoming solar radiation and net radiation were not possible ; the response times of the two instruments are about 30 and 50 second respectively. In clear weather, this was not generally a problem as the values were stable and could be checked by reading in series $\downarrow$, Q^*, $K\downarrow$.

The use of these portable instruments allowed point sampling of a wide variety of surfaces representing the essential units making up the landscape, as well as a number of different sites for any given surface type. At each site, the pyranometer was set up and levelled at or near the ground, to give the best exposure possible. The net radiometer was levelled at 1.2m above the ground in the case of each surface type, in order to sample a sufficient area. At certain observations such as those during a light, cold, moist low-level drift of air from the sea, the difference in the net radiation measured at 1.2m and that for the actual surface may have been significant (Idso and Cooley, 1971 ; Kondo, 1972). No correction has been attempted. All sites were near horizontal.

Although a few observations were taken at other sites in the coastal zone illustrated in Figures 2a, b, the majority of measurements were made within the main study area indicated, where a representative variety of surface conditions was found in convenient proximity (Figure 3). Point observation procedures included careful visual scrutiny of sky and atmospheric conditions and of the nature of the surface, including its degree of wetness or dryness and of pollution. The periods of sampling included late May/June, 1972, August to early October 1973, June to September 1974 and June 1975.

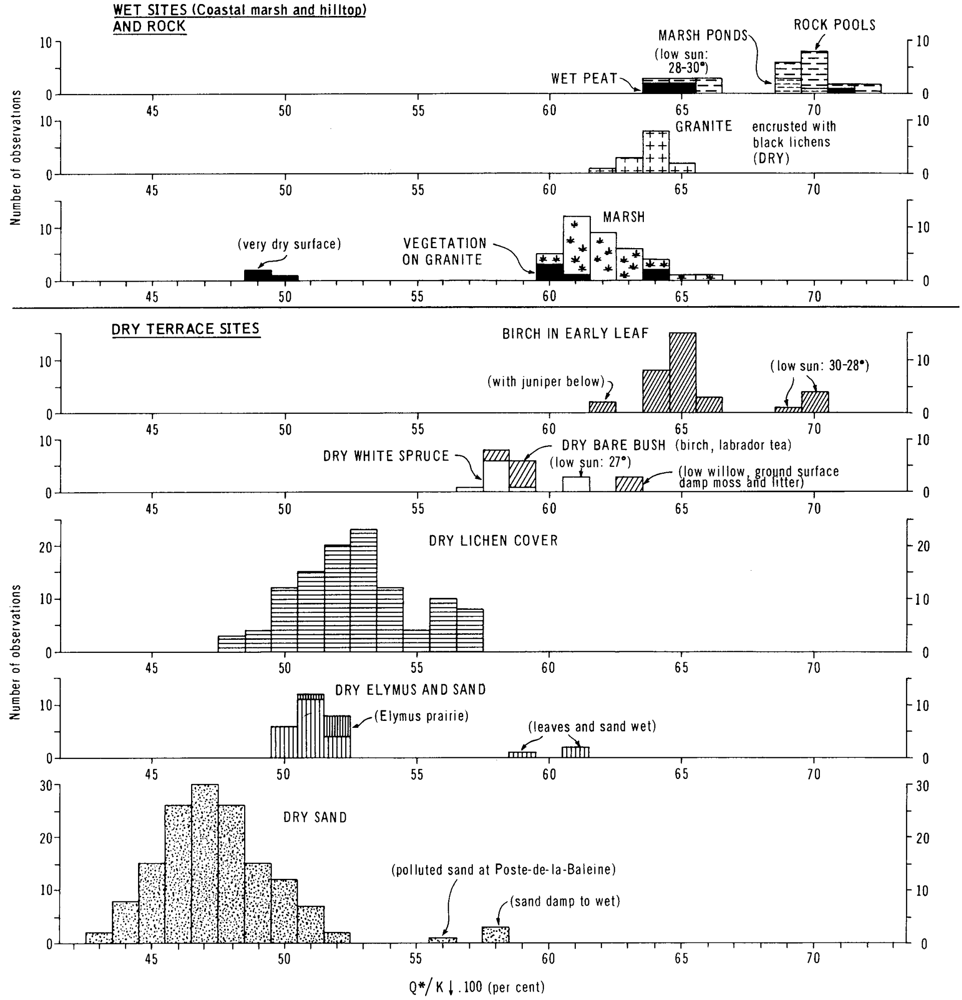
The analysis of the data is based on the simple linear regression equation relating Q^* and $K\downarrow$:

$$Q^* = aK\downarrow + b. \qquad (2)$$

The past performance of this model in different climatic zones and for various weather and surface conditions has been consistently promising. For climatological purposes, results suggest that the accuracy of prediction of net radiation can be increased to within instrumental accuracy (5 to 10%) by careful stratification of the data according to weather and surface types, and by the use of hourly or point-fluxes to ensure a better distribution of values, including data near the origin (cf. Fritschen, 1967 ; Idso *et al*, 1969). However, the technique remains a black-box procedure incorporating the many fluctuations of differing sense. Several investigators have attempted to refine the equation in terms of coefficients related to the response characteristics of the different surfaces, thus permitting a

Figure 4

POSTE-DE-LA-BALEINE: Net radiation as a percentage of incoming solar radiation, in clear weather during the snow-free season. (Point fluxes.)



more precise interpretation in physical terms. Monteith and Szeicz (1961) introduced the reflection coefficient, and, assuming L* to be a linear function of Q*, defined a characteristic « heating » coefficient, β, believed to be associated in clear weather with the net long-wave loss at the surface; in widespread application, β values were found to differ greatly and inconsistently, and to have no predictive value. More recently Gay (1971) has proposed a new long-wave coefficient, λ, in which L* is treated as a function of K$\downarrow$. The consistency and meaning of this coefficient have yet to be ascertained. The estimate of net radiation does not appear to be improved by the inclusion of the surface reflection coefficient (cf. Fritschen, Idso *et al.* ; also Davies and Buttimor, 1969, Impens and Lemeur, 1969).

In a critical reappraisal of the regression model in relation to radiation fluxes over Prairie grass, Nkemdirim (1972) re-emphasizes that its value is descriptive and predictive, rather than explanatory. The original equation has the advantage of simplicity.[6]

RESULTS

Histograms of the ratio $Q^*/K\downarrow$ for the different surfaces are given in Figure 4. The influence of the surface on the ratio can be summed up as follows :

1. — relatively low values occur for bare soil and dry vegetation. The amount of the soil surface actually covered by vegetation is significant ;

2. — values are high for open water and wet surfaces ;

3. — the ratio increases with the height of the vegetation cover and the completeness of the canopy ;

4. — high values also occur for many types of rock.

For comparison, the regression curves for the various surface types are shown together in Figure 8.

Dry sand

$$Q^* = 0.476\ K\downarrow - 2.1\ Wm^{-2}.\quad N = 143,\ r = 0.984.$$

Standard error of estimate, 11.9 Wm^{-2}.

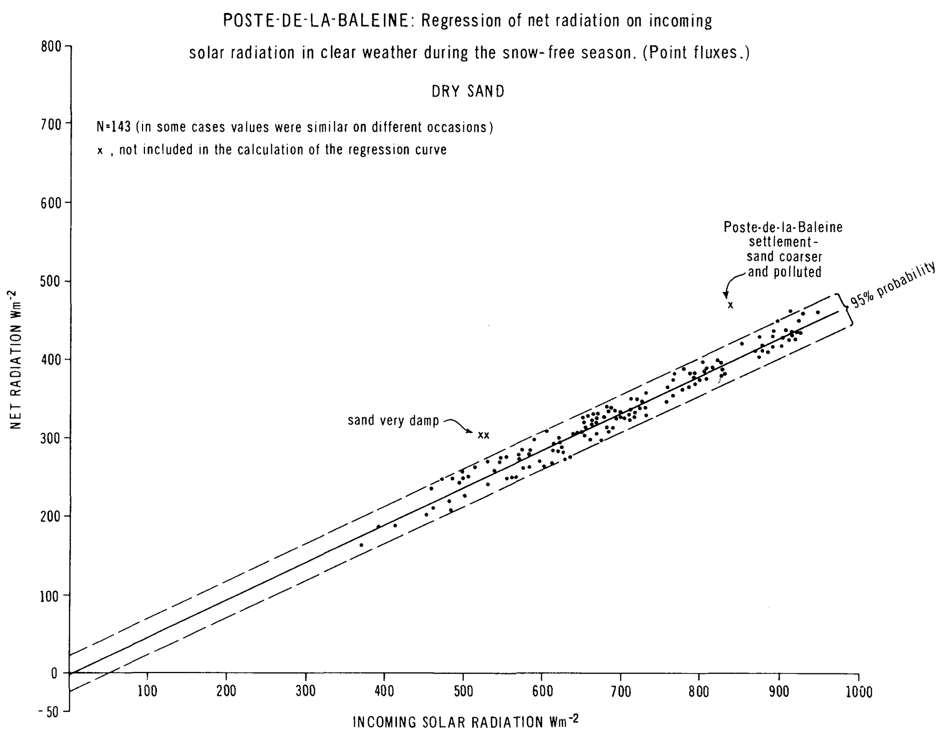
Bare sand is now a dominant surface type in the coastal landscape of Poste-de-la-Baleine. The well-drained beach ridge terraces have provided the most readily available sites for building the settlement and runways, and this has resulted in the blanket removal or destruction of the Elymus prairie and lichen cover over large areas, leaving a desolate desert of loose and often dirty sand. Since the airphoto (Figure 2b) was taken in 1959, the settlement has been extended towards the coast and runways. To the north, increasing vehicle traffic has hastened the destruction of the protective vegetation cover (still seen in Figure 2b) from the upper beach ridge terrace just south of the Geophysical station (Figure 2a) ; this now forms a bare deflation zone (cf. Figure 3a).

Observations were made on 18 days : May 28, 30, 31, June 2, 4, 1972 ; August 18, 1973 ; May 30, June 5, 14, 22, 23, 24, 25, July 10, August 8, 14, 15, 21, 1974. The sun's height above the horizon ranged from 58° to 24°. Air temperature and absolute humidity at the times of observation varied from 24°C to −1°C, and 14 mb to 4 mb ; winds were either from the land (on occasion as strong as 7m sec^{-1}), or from the NNW-WNW and generally light. The variability of the ratio $Q^*/K\downarrow$ (Figu-

[6] A more detailed discussion of the literature, with special concern for Québec regions, is included in the reference, WILSON (1975).

res 4 and 5) depended on the degree of dryness or pollution of the surface and atmosphere, and the presence or absence of very light cirrus. Increasing surface humidity or pollution, increasing low-level background aerosol, or the presence of cirrus, usually resulted in a rather higher proportion of net radiation, while increasing clarity and dryness of the atmosphere and very dry sand gave the lowest percentage values recorded in the coastal area. The regression curve is shown in Figure 5.

Figure 5



While the sand forms one of the most homogeneous of natural surfaces, changes occurred from time to time within the main study area as a result of some soiling by frequent vehicle traffic, and the later redistribution of this sand by wind action. After periods with strong winds, the organic horizon associated with the underlying du Poste series was occasionally exposed, or lay near the surface, and some fine organic matter was mixed with the surface sand. An extreme case of pollution, measured over the dry, dirty, coarser sand in the settlement of Poste-de-la-Baleine, is shown in Figures 4 and 5 ; the ratio of 56% compares with a value of 48% obtained 30 minutes later, over dry, clean medium-grained sand in the main study area, under similar atmospheric conditions and solar angle (~50°).

Important differences in the reflectivity and thermal conductivity also occur through surface changes in the dryness of the sand. Dry sand has a low thermal conductivity ; when it is wetted, this increases to 5 to 8 times the dry value (cf. Geiger, 1965). At the same time, the reflectivity is reduced to about one half of that for dry sand (Ångström, 1925). The dryness of the sand was assessed visually and by touch, taking into consideration the occurence of past precipitation and the drying capacity of the air. With clearing skies and/or strong winds from the land, the drying out of the immediate surface was usually rapid. Once a thin surface layer had dried out ($<$ 3cm), the degree of dampness below appeared to have no significant effect on the retention of radiant energy. Three cases in which the sky was clear but the sand surface and subsurface were damp have been plotted on Figures 4 and 5 ; the corresponding ratios of 58% can be compared with a value of 44% for very dry sand at that site, under similar weather conditions and solar angle (31°). The data for the damp sand fall close to the curve for the closed marsh sites, and the values could be predicted by that regression equation with an error just within the 95% confidence limits.

With respect to atmospheric conditions, an increase in humidity while reducing the total incoming solar radiation at ground level, did not appear to affect the proportion of net radiation. For example, with very clear sky conditions on August 18, 1973 (temperature 23-24°C, vapour pressure 12-14 mb, winds NNE, N, 4 to 7m sec^{-1}), incoming solar radiation was 6% less than comparable measurements on August 22 (12°C, 9 mb, WNW, NNW, 2 to 4m sec^{-1}), yet the percentage of net radiation remained on the low side. On the other hand, in the presence of an almost invisible veil of cirrus on August 15, the percentages increased. This question is being studied further.

Considering the diurnal variation in the reflective power of dry sand (Table 1), percentage values of $Q^*/K\downarrow$ were plotted against solar altitude. Within the range of measurement (solar angle 58° to 24°), very little change was noted. For very clear, dry conditions (August 18, 1973, June 23, 25, August 21, 1974), there was a slight decline in the percentage with lower sun. On some days when very light cirrus or very light wafts of low-level cumulus were present, there was a suggestion of an increase in the percentage with decreasing angle. In general, values were slightly higher in the morning than in the afternoon. The immediacy of the response of the dry sand surface in rapidly heating and cooling – a result of its low thermal capacity and conductivity – probably offsets the variation in the reflected component of the incoming solar radiation.

Elymus Arenarius

$$Q^* = 0.519\ K\downarrow - 7.0\ Wm^{-2}.\quad N = 21,\ r = 0.997.$$

Standard error of estimate, 3.5 Wm^{-2}.

The Elymus site was one of blown sand covering the du Poste Series on the higher set of beach ridges (Figure 3). The grass (45 to 60 cm high, green leaves, golden stalks and ears) and the sand surface were very dry, but at 5 cm below, the sand was still damp. Measurements were made during one day only (August 19, 1973), the solar altitude ranging from 47° to 25°. The day was « clear » throughout, though haze was reported. Before noon, the air temperature was 26 to 29°C, with light S to SSE winds ; this dropped to 21 to 23°C after noon, with a light NNW breeze. Absolute humidity increased from an average 12 mb in the morning to 15 in the afternoon. Comparing $K\downarrow$ for the early afternoon with that for August 22 (12°C, WNW wind, absolute humidity 9 mb, excellent visibility) showed a 5% reduction in incoming solar radiation on August 19. This suggests that with a larger sample, the slope of the regression curve (Figure 8) might be slightly less steep ; the standard error would be expected to increase. There was little diurnal variation : a slightly higher percentage of net radiation between noon and 14 hr (local apparent time), and slightly lower early morning and late afternoon. In spite of the height of the Elymus cover, the ratio $Q^*/K\downarrow$ remains relatively low. This is probably due not only to the exposed sand, but to the high reflectivity of tall grass when it is dry (Ångström, 1925).

For comparison, the same site was measured in clear weather (October 2, 1973, solar angle 31°), when the grass and sand were wet after rain (Figure 4). The tops of the leaves were turning yellow, but the lower part was still green : water droplets glistened on the leaves, but the ears seemed less wet. Under these conditions, the Elymus appeared to respond similarly to that of the closed marsh, and it was possible to predict the net radiation using that regression equation with errors of 6 to 13 Wm^{-2}, well within the 95% confidence limits.

A series of measurements was also made on the Elymus prairie on the lower beach ridges (Cordon Series), on June 5, 1974 (solar angle, 46 to 47°). The Elymus was young growth, associated with mosses, lichens, other grasses, sea-pea and crowberry to give a complete, predominantly green cover. The air was very clear and dry (vapour pressure, 4 mb), with considerable drying power (vapour pressure deficit 16 mb, winds ESE at 6-7m sec^{-1}, 18°C). As a result, the surface was very dry to the touch. The observed values fell very close to the Elymus curve (cf. Figure 4), and could be predicted by that equation to within 3 to 11 Wm^{-2}.

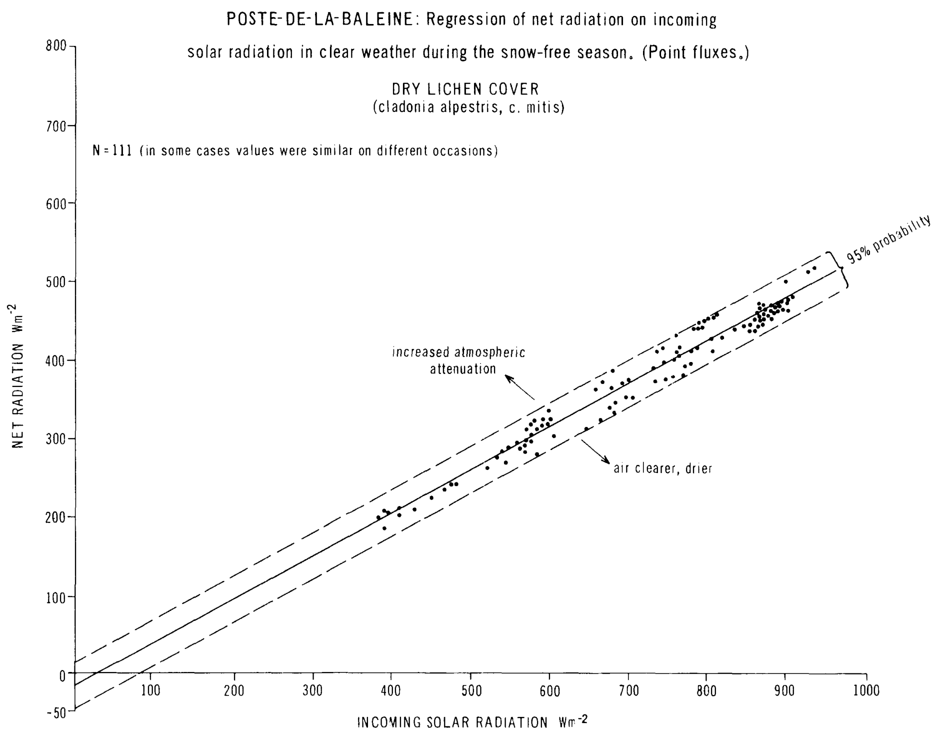
Dry lichen cover (Cladonia alpestris, C. mitis)

$$Q^* = 0.549\ K\downarrow - 15.4\ Wm^{-2}.\quad N = 111,\ r = 0.985.$$

$$\text{Standard error of estimate, } 14.7\ Wm^{-2}.$$

The main lichen sites consisted predominantly of *Cladonia alpestris* and *C. mitis*, which formed the floor of a small area of open lichen woodland on a stabilized bench of eolian origin ; differences in the brightness or surface structures of the lichens did not seem to be significant. In clear

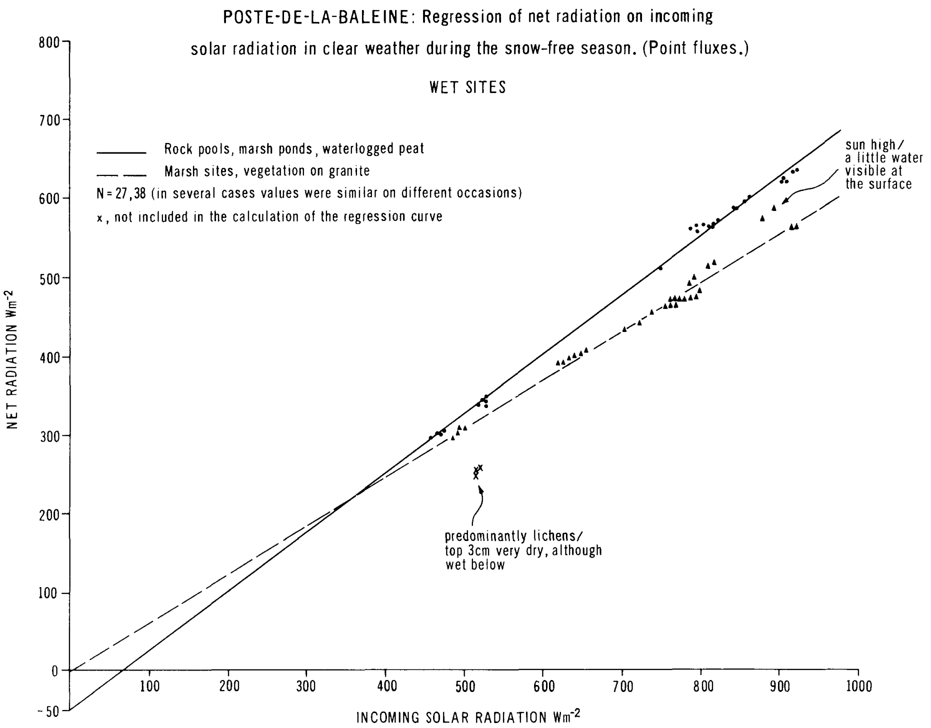
Figure 6



weather, the upper surface layer of the non-vascular lichens dries out rapidly, changing from a soft, dense, sponge-like texture to a hard, brittle, highly reflective material (Table 1). With continuing dessication, the middle and lower layers of the lichens lose their moisture, but more slowly (cf. Rouse and Kershaw, 1971), as dry lichen has a low thermal conductivity and forms an effective insulator. As the previously closed canopy dries out, the lichen cover contracts ond separates to form polygons. The underlying organic debris and soil generally remain very damp, except where exposed in the cracks, and at the edge of the polygons. At the sites measured (cf. Figure 3), the lichen cover varied in depth from 3 to 7 cm. In all cases the lichens were very dry.

Measurements were taken on 8 days : May 31, June 2, 1972 ; August 20, 22, 1973 ; June 5, 7, 1974 and June 7, 8, 1975. Solar altitude at the times of observation ranged from 58° to 25°, air temperatures from 30°C to 4°C, vapour pressure from 16 to 4 mb, winds either from the land (4 to 11 m sec^{-1}) or from the WNW, NW, light. The results are shown in Figures 4 and 6. Although the reflection coefficient for dry lichens shows a marked dependence on solar altitude (Table 1), there appeared to be no significant change in the ratio $Q^*/K\downarrow$ with angle of incidence, although the percentage values tend to be slightly higher in the early morning than in

Figure 7



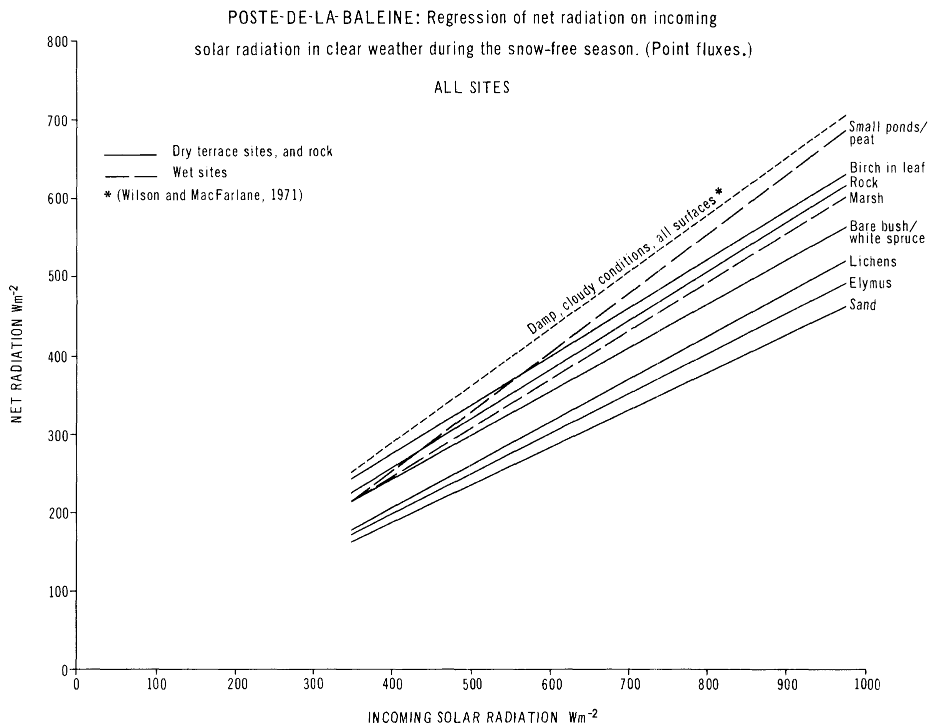
the late afternoon. Rather like the sand, the dry lichen surface appears to respond very rapidly to changes in incoming radiation.

The variability shown in Figures 4 and 6 was largely the result of differing atmospheric conditions, the lowest ratios of $Q^*/K\downarrow$ referring to those times when the air was clearest and driest. The following cases illustrate the influence of atmospheric attenuation on net radiation :

1. — On June 7, 1974, with air temperature at 29°C, vapour pressure 13 mb, and relative humidity 31%, a strong SSW flow of 11 m sec^{-1} created a pall of blowing sand. Traces of very light cirrus were also present. At high sun (55 to 56°), the values of incoming solar radiation were 10% lower than for similar observations on June 5 – a cooler, drier day without blowing sand (17°C, 4 mb, 22%, ESE, 5 m sec^{-1}). However, the corresponding reduction in net radiation on June 7 was only 4%, and the ratio of net to total incoming solar radiation *increased* by more than 3% to 56%.

2. — August 20, 1973 was a very warm, hazy day (29° C, 16 mb) with a light veil of cirrus and occasional cirrus streaks ; winds were SSW, 7 m sec^{-1}, gusting to 12 m sec^{-1}. Compared with corresponding values (solar angle 38-39°) for August 22 – a cooler, drier day (12°C, 9 mb), with very light WNW flot – $K\downarrow$ on August 20 was 12% lower, although the net

Figure 8



radiation values were the same on both days, giving an average *increase* in the ratio $Q^*K{\downarrow}$ of 7% (from 49 to 56%).

3. — On June 7, 1975, a mild relatively dry day (14°C, 9 mb, winds NNE, 6 m sec^{-1}, light cirrus and haze were present together with very light wafts of low-level cumulus. Compared with corresponding measurements solar angle 57°-30°) made on June 8, – a cool, very clear day (7°C, 8 mb, very light NW winds) – $K{\downarrow}$ was 3% lower on June 7, while Q^* was 3% *greater* ; the ratio $Q^*/K{\downarrow}$ *increased* by 3%, from 51 to 54%.

In general, a very light film of cirrus, blowing sand, or very light wafts of low-level cumulus increased the amount of energy available at the lichen surface relative to the incoming solar radiation (Figure 6). It also appears that the *absolute* values of surface net radiation can be greater under certain conditions of atmospheric attenuation, than when the air is clearer and drier. This is in keeping with Idso's (1975) observations during a weak duststorm in Arizona, for which he calculated an increase in downward atmospheric radiation of about 10%, although the increase in background low-level aerosol content was small and the reduction in $K{\downarrow}$ negligible. In Idso's case, the surface was one of bare wet soil.

Once the sun was shining, the surface of the lichens dried so rapidly that the case of damp lichen surfaces in clear weather was not easy to obtain, and no measurements are available.

White spruce and bare bush. (Picae glauca agg., Betula glandulosa agg., Ledum palustre agg.)

$$Q^* = 0.561\ K\downarrow + 18.8\ Wm^{-2}.\ N = 20,\ r = 0.997.$$

Standard error of estimate, 6.3 Wm^{-2}.

Thirteen observations were made over small white spruce trees (height ~1 m) on the beach ridges (du Poste), on the stabilized eolian slopes, and on the sandy edge of a granite outcrop near the coast. In each case, the radiometer was close to the high point of the tree, although well above the flare. With isolated trees, the influence of the surrounding sand, crowberry or lichen floor may have been responsible for the rather higher reflection coefficient and rather lower percentage of net radiation than might have been expected. The spruce needles were in all cases very dry. Measurements were made on May 31, June 2, 1972, June 5 1974 and October 3, 1973. In late spring, the sun's angle of incidence was 50-57°, in the early afternoon of October 3, 27-26°. The higher percentage of net radiation at low sun (Figure 4) is probably related to the near vertical surfaces presented by the trees. Ångström (1925) has noted the importance of solar radiation reflected from near shore waters at low sun on the coasts of higher latitudes (Table 1), in that such vertical surfaces can profit from an increase in total solar radiation received. Over the period of observations, winds were mainly from the land, temperatures ranged from 4° to 18°C, absolute humidity from 4 to 5 mb.

On June 5, 7 pairs of values were also obtained for low birch bushes and Labrador tea at solar angles from 42° to 53°. The birch cover on the Annei series in the gully was about 50 cm high, a complex of small brown branches prior to leafing, with some juniper, dry moss, grass and litter below. There had been less snow than usual, and a rapid melt during two weeks of sunny weather in late May ; the water level in the nearby stream was low, and the ground surface at the site was dry. The Labrador tea occurred near the contact of granite and the du Poste series, and formed a relatively dense brown cover about 40 cm high on dry sand. The net radiation and incoming solar radiation values fall on the same curve as that for the spruce [7], suggesting that before the new green canopy has appeared, the same curve can be used to estimate the net radiation. The openness of the cover to expose the more highly reflective ground cover or sand, as well as the polished surfaces of the birch branches, may result in a rather higher reflectivity at this part of the season, offsetting any increased capture or retention of energy owing to the colour and height of

[7] For the white spruce alone, the regression equation was:

$$Q^* = 0.559\ K\downarrow + 20.9\ Wm^{-2}.\ N = 13,\ r = 0.997.$$

Standard error of estimate = 7.7 Wm^{-2}.

the vegetative matter. At low sun, with less penetration to ground level, an increase in the percentage of net radiation would also be expected. The regression curve for white spruce and brown bush is shown in Figure 8.

The significance of the dryness of the exposed ground surface is suggested by measurements made on May 31, June 2, 1972 (48°-57°) over bare willow (*Salix glauca* L.), ~40 cm high, in the gully (cf. Figure 4). The spring melt had been late, the weather cool, and both the soil and ground cover of mosses and litter were damp.

Birch in early leaf (Betula glandulosa)

$Q^* = 0.617\ K\downarrow + 26.5\ Wm^{-2}$. $N = 31$, $r = 0.998$.
Standard error of estimate, 7.0 Wm^{-2}.

The increase in net radiation at the birch site after the appearance of the leaves is shown in Figures 4 and 8. However, the warm summers of 1973 and 1974 had encouraged an increase in the height of the birch to about 75 cm, which must be taken into consideration. The leaf canopy was not quite fully extended, exposing some branches and to a small extent the dry grass, brush, wood and litter at the floor. Measurements were taken on June 7 and 9, 1975 (solar altitude 58°-28°) ; winds were light NNE and WNW respectively, temperature 9° to 12°C, absolute humidity about 9 mb, with a very light cirrus veil about noon. As the sun's altitude decreased below 30° in the late afternoon, the percentage of net radiation rose. The geometry of an individual site also enters into play here.

Sampling of a nearby site on June 7 (high sun), where juniper formed a substratum, showed slightly lower net radiation in keeping with the rather higher reflection coefficient recorded on June 6 (Table 1).

No measurements are available for the early autumn, when the leaves turn orange. From Federer's (1968) observations for a hardwood forest in New England, an increase in surface reflectivity would be expected.

Granite

$Q^* = 0.626\ K\downarrow + 7.0\ Wm^{-2}$. $N = 14$, $r = 0.998$.
Standard error of estimate, 5.6 Wm^{-2}.

The number of observations is small. Measurements were made on the granite platform (cf. Figure 3) above the beach ridges. The dry rock surfaces were dark with brighter light grey crystals, generally encrusted with black lichens and occasional patches of minute green lichens. Three days were sampled, July 4, June 5, 1974 and October 3, 1973, at corresponding solar altitudes of 55°, 43-44° and 29°. Winds were from the NNE, E and ESE and brisk on July 4 ; temperature and vapour pressure ranged from 18° to 5°C and 11 to 4 mb, respectively. On October 3, slight cirrus may have been present. The percentages of net radiation were slightly higher in the morning than early afternoon ; no late afternoon observations are available. The large percentage of net radiation (Figures 4 and 8) is related to the high thermal conductivity of the rock.

Marsh and Vegetation on granite

$$Q^* = 0.622\ K\downarrow - 2.1\ Wm^{-2}.\ N = 38,\ r = 0.989.$$
Standard error of estimate, 11.2 Wm^{-2}.

Observations were made on the coastal marsh, where the gully opens out at the level of the lower beach ridges, in the contact zone with the granite outcrop nearby and over mesic and humid sites in the small granite hilltop depressions (cf. Figure 3). The marsh sites consisted of sphagnum moss and sedges, with a relatively dense growth of coarse grass (*Calamagrostis*), 35 cm high, and occasional ground willow ; very little water was actually visible. Near the contact with the granite, the cover included mosses, lichens, crowberry, blueberry, ground willow and low herbs. Where the motor cycles and skidoos cross this zone, the vegetation has been churned in, and the black to very dark brown organic layer is exposed. Although the upper surfaces of the vegetative layer were at times dry, the sub-surface and soil were usually saturated. In the hill top depressions, mosses, lichens, crowberry, grasses and ground willow presented a predominantly green spongy cushion on a wet, black organic layer. At some sites there was a higher proportion of lichens (*C. alpestris, mitis*), the upper parts of which tended to dry rapidly in the clear weather, although the subsurface, the soil and the mosses remained wet.

The measurements refer to June 2 1972, June 5, July 4, August 23, 1974 and October 3, 1973, the solar altitude ranging from 57 to 29°. Temperatures varied from 5 to 18°C, the absolute humidity from 4 to 10 mb ; winds were from the land, or calm, and the sky appeared clear except for a slight cirrus haze on October 3.

Figures 4 and 7 show the spread of percentage of net radiation and of the measured values. There is a natural lack of homogeneity in these wet sites with respect to the amount of water at the surface, the dampness of the top of the vegetative layer and the height and nature of the vegetation. For sedge meadow, Davies (1969) stressed the influence of the very small amount of water actually visible, in relation to its reflectivity. The coefficient that he obtained (16%, Table 1) is similar to that published by Berglund and Mace (1972) for sphagnum-sedge bog in Minnesota. Table 1 also shows the lowering of the reflectivity when the surface has been disturbed by traffic, which effectively exposes some of the black waterlogged soil. On the other hand, the high reflectivity of tall grass, when it is dry, has been demonstrated by Ångström (1925). In Figure 7, two points are noted as referring to marsh sites where a little water was actually visible at the surface ; with the sun 54 to 55° above the horizon (and penetrating the tall grass), a marked increase in the absorption of solar radiation has resulted. With an increasing amount of surface water, the values approach the curve for small ponds.

When the upper surface is dry, the spongy carpet of vegetation on the wet soils at the edge of the marsh and in the granite depressions has a relatively high reflectivity (Table 1). This is further emphasized by the presence of lichens, which effectively insulate the underlying layers. The graphs (Figures 4 and 7) show values measured on October 3 (solar angle 31°) over a very dry surface of predominantly lichens with crowberry. Below, the mosses and black soil were very wet. These observations fall well within the values obtained for dry lichens on the dry sandy sites of the beach ridges – and have been omitted from the regression equation.

Rock pools, marsh ponds and wet peat

$$Q^* = 0.757\ K\downarrow\ - 50.3\ Wm^{-2}.\ N = 27,\ r = 0.998.$$
$$\text{Standard error of estimate, } 8.4\ Wm^{-2}.$$

The percentages and values for those sites with a predominantly water surface are shown in Figures 4 and 7. Observations were taken on June 2, 1972, June 5, July 4, 1974 and October 3, 1973 (solar altitudes 57° to 28°). Air temperatures ranged from 18 to 5°C and the absolute humidity from 11 to 4 mb, correspondingly ; winds were from the land, light to moderate, or calm. The rock pools sampled on the granite platform were 2 to 3 m wide, the water 8 to 16 cm deep and very clear (cf. Figure 3). The bottom of the pools was of black/brown rock, with a few grains of gravel or sand but no vegetation. The watery marsh sites included a shallow pond (10-20 cm deep), with dark grass lying on a sandy bottom, flooded marsh vegetation and peat covered with a thin layer of water.

Although at high sun the reflection coefficient for a water surface is small, at low sun the reflectivity increases rapidly (cf. Table 1), and this is shown in the steepness of the regression curve, and the convergence of the two curves for wet sites (Figure 7).

In summary, the average value of $Q^*/K\downarrow$ for the various dry terrace sites was 54%, the marsh sites 66%. For the granite outcrops, the average was 63%, but rose to 66% if the dried lichen surface were omitted. These values do not include areal weighting.

CONCLUSION

1. — An inexpensive method has been used to predict the energy available in clear weather at different northern surfaces in the region of Poste-de-la-Baleine from relatively limited field observations. Such an approach offers a first approximation useful in ecological studies, including northern development programmes, and a tool for the analysis of some aspects of the seasonal energy climate and their variability.

2. — Current and projected development of the James' Bay – Hudson's Bay drainage basins in Northern Québec implies considerable change in the ecology of the coastal region. Building and construction projects usually engender the mass removal of trees, bush, lichens and Elymus from the terrace sites and the filling of lowland marsh ; that is, a reversion to sand.

Figure 8 summarizes the relations between net and solar radiation for the different surfaces, and it can be seen that all such changes reduce to a minimum the retention of energy at the natural surface, in clear weather. In damp, cloudy weather, such modification appears to have little effect on the energy available.

3. — From the point of view of energy exchanges, plant growth and the creation of favourable microclimates near the ground, the importance of clear weather in the ecology of the area would appear to be much greater than its limited frequency might suggest. Bunting [8] has remarked that while plants are adapted to the general temperature regime, it is the variation in radiation received (as well as summer drought), which is responsible for variations in yield. Miller and Tieszen (1972) found that primary production in the arctic tundra increased with solar radiation, but was not affected by infrared radiation from the sky or ground. At Poste-de-la-Baleine, the abnormally sunny growing seasons of 1973 and 1974 resulted in a luxuriant surge of plant growth, especially in the more sheltered sites, which could profit most from the increase in solar energy received. In a discussion of « warming devices » in a number of arctic plants and insects, Corbet (1972) emphasizes that they rely on direct solar radiation and stresses the importance of the proportion of sunny days in summer, as a climatic statistic.

4. — With respect to the application of the regression curves, two further studies are currently being undertaken :

a) to estimate the frequency of such atmospheric and surface conditions during the snow-free season, by defining the limiting factors at the times of the field observations in terms of more readily available meteorological data (cf. Wilson, 1972);

b) to map the available energy by incorporating the effects of slope and aspect.

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[8] A.H. Bunting, in a lecture on *Time, phenology and the yield of crops,* presented at a meeting of the Royal Meteorological Society in London, December 18, 1974.

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ABSTRACT

WILSON, Cynthia: Net radiation during clear weather in the snow-free season for various types of surface, Poste-de-la-Baleine (Great-Whale), Québec.

During the snow-free seasons 1972-1975, point fluxes of net radiation (Q^*) and incoming solar radiation ($K\downarrow$) were measured in clear weather for different surfaces near Poste-de-la-Baleine (Great Whale), Québec. The relationship between Q^* and $K\downarrow$ is described for each type of surface in terms of the simple ratio $Q^*/K\downarrow$, 100% and the linear regression curve, to enable estimates of net radiation to be made from the more available measured or calculated $K\downarrow$.

The results suggest that the use of portable instruments for relatively short periods of carefully controlled field observations offers an inexpensive method of predicting net radiation in the less accessible north, if the measurements are stratified according to weather and surface conditions. A comparison of the regression curves permits a simple quantitative estimate of the potential differences in the net energy at the surface, resulting from projected changes to the terrain with northern development. The curves in this present article refer to clear weather. Although it is relatively rare on this coast, it is believed to have an importance in the energy climate and ecology quite beyond its limited frequency.

KEY WORDS : Climatology, net radiation, New Quebec.

RÉSUMÉ

WILSON, Cynthia : Le bilan du rayonnement pendant la saison sans neige à Poste-de-la-Baleine (Great-Whale), Québec, par temps clair et pour différents types de surfaces.

De 1972 à 1975, pendant les saisons sans neige, par temps clair, nous avons relevé des flux ponctuels du bilan du rayonnement Q^* ainsi que du rayonnement solaire global $K\downarrow$, pour différentes surfaces situées près de Poste-de-la-Baleine (Great Whale), Québec. Pour chaque type de surface, nous décrivons les relations entre Q^* et $K\downarrow$; d'abord les rapports de $Q^*/K\downarrow$ .100%, puis les courbes de régression linéaire, pour permettre l'évaluation du bilan du rayonnement à partir de données plus facilement disponibles de $K\downarrow$, soit mesurées, soit calculées.

En groupant les mesures selon le type de temps et les conditions de la surface, les résultats suggèrent que l'emploi d'instruments portatifs et la collecte soigneuse d'observations pendant des périodes relativement courtes constituent une méthode peu coûteuse pour prévoir le bilan du rayonnement dans des régions peu accessibles, notamment les régions nordiques. La comparaison des courbes de régression permet une évaluation quantitative des différences potentielles en énergie nette de surface, qui pourraient s'effectuer en relation avec des changements dans la nature de la couverture du terrain prévus dans le développement du nord. Les courbes présentées dans cet article se réfèrent au temps clair. Bien que ce type de temps soit relativement rare sur cette côte-ci, il aurait, dans le climat énergétique et dans l'écologie, une importance bien supérieure à sa fréquence assez restreinte.

MOTS CLÉS : Climatologie, bilan du rayonnement, Nouveau-Québec.