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McGILL UNIVERSITY
Department of Geography

CLIMATOLOGICAL BULLETIN

NO. 3
JANUARY 1968

McGILL UNIVERSITY, MONTREAL

CLIMATOLOGICAL BULLETIN

CONTENTS

No. 3 January 1968

CLIMATOLOGICAL BULLETIN is published in January and July each year. It exists to report on the work associated with the programme of Graduate Training and Research in Climatology and Microclimatology in the Department of Geography at McGill University which is supported by grants in aid from the National Research Council of Canada, the Department of Transport (Meteorological Branch) and the research funds of McGill University. Any additional special support is acknowledged in the relevant article. The Department also publishes a CLIMATOLOGICAL RESEARCH SERIES, information on which will be found at the end of this Bulletin.

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FOREWORD

CLIMATOLOGICAL BULLETIN enters its second year of existence similar in content and format to the two numbers produced in 1967. Two new sections which will become regular features of the BULLETIN consist of (a) Research Report, and (b) News and Comments. These are intended to provide informal information on the climatological programme and matters related to it. The section providing selected climatic data at Mont St. Hilaire has been dropped. The station is now incorporated in the Canadian Meteorological Network and observations are, therefore, reported regularly through the normal channels of the Department of Transport.

Although the BULLETIN is intended mainly as a publication medium for those associated with the climatological programme at McGill University, relevant contributions and correspondence from those who are not direct participants are also invited.

B. J. GARNIER,
Professor of Climatology,
Department of Geography,
McGill University,
Montreal.

January, 1968.

THE CLIMATE OF BARBADOS

by

D. G. TOUT*

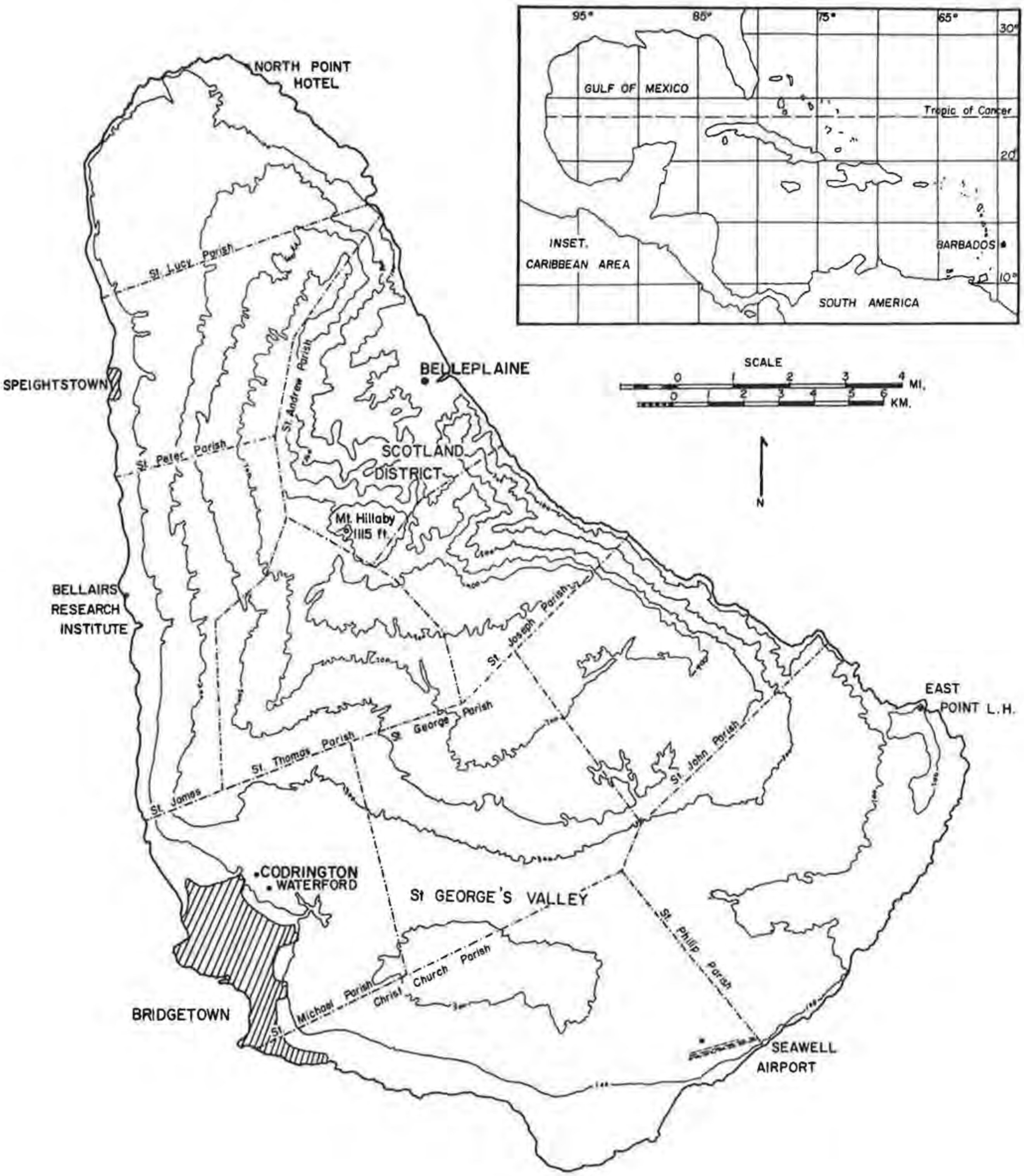
Introduction

Barbados is a small island situated in latitude 13° 02' - 13° 20'N and longitude 59° 25' - 59° 39'W about 100 miles to the east of the main chain of the Windward Islands (Fig. 1). To the east of the island the tropical North Atlantic Ocean extends 3,000 miles to the coast of West Africa.

Whereas the Windward Islands are of volcanic origin, approximately six-sevenths of the surface of Barbados is composed of coral limestone. The remaining one-seventh, the Scotland District, consists of less resistant rocks where the coral cap has been removed. Soil erosion is a severe handicap to development in this latter region. The total area of the island is 166 square miles compared with the 1,980 square miles for Trinidad and Tobago.

At Mt. Hillaby in the parish of St. Andrew, the land reaches its highest point (1,115 ft) and from the summit of this hill much of the island is plainly visible to an observer. To the west, the land falls in a series of sugar-cane covered coral terraces to the tourist resorts of the west coast. To the north-east the more diversified ridge and valley country of the Scotland District focuses on the settlement of Belleplaine. South-

* D. G. Tout has an M.Sc. degree in Geography (Climatology) from McGill University and is now studying for a Ph.D. degree at the University of Reading, England. He was in charge of the McGill University Climatology Station in Barbados from 1963-1965.



BARBADOS

LOCATION MAP

FIG. I

wards the land falls gradually to the east-west through a valley known as the St. George's Valley. South of this valley the land rises to 400 feet in the Christ Church Ridge and then descends evenly to the south-west coast. Apart from the built-up area of Bridgetown and its suburbs and the semi-arid areas in the south-eastern parts of the parishes of Christ Church and St. Philip, most of the southern part of the island is devoted exclusively to growing sugar cane.

General Factors Controlling the Island's Climate

Barbados is surrounded by a tropical sea which has a temperature varying little from 80°F in any month of the year. The nearest land area is 100 miles to the west. Daily solar radiation at the top of the atmosphere for latitude 13° 20'N varies from 719 langleys (lys) to 932 lys over a twelve month period (Tout, 1967). During the months with low radiation values at the top of the atmosphere cloud amounts are low and radiation is strongly absorbed at the surface of the earth. In June, July and August when radiation values at the top of the atmosphere are high the cloud amount is also high, as this is the rainy season, and a lower percentage of radiation reaches the surface. As a result of these conditions monthly values of total solar radiation on a horizontal surface do not show great differences from one month to another. The months of March, April and May are exceptions to this statement, however, since high radiation values combine with low cloud amounts at the end of the dry season to give high values of total solar radiation at the surface. The fact that monthly values of radiation on a horizontal surface are always high and the surrounding seas are always at a temperature of about $80^{o}F$, means that monthly temperatures on the island will vary little and will always be near the mean ocean temperature. As in any maritime situation, diurnal ranges of temperature will be small. In fact, we find that temperatures rarely rise above $90^{o}F$ or fall below $60^{o}F$. The more elevated parts of the island, however, experience temperatures slighly lower than these.

For the greater part of the year Barbados lies in the broad stream of the North Atlantic Trade Winds which generally blow from directions between east north-east and east south-east in these latitudes. These winds have an uninterrupted sea-passage from their source region in the vast anticyclonic area normally situated near the islands of the Azores in latitudes 35^{o} - $40^{o}N$. On travelling south-westwards these winds pick up warmth and moisture from the underlying tropical ocean and the associated maritime tropical air mass, with high levels of relative humidity, will produce instability rain showers when forced ascent takes place, provided that the trade-wind inversion level is sufficiently high.

During the rainy season months, June through November, the island occasionally comes under the influence of the Inter-tropical Convergence Zone (ITCZ) which is usually found at its most northerly position, about $10^{o}N$ latitude, during the months of July and August. Its influence at this season may, at times, extend to $15^{o}N$ latitude accompanied by increased convectional activity and wind from a more southerly point. During the rainy season Barbados is also visited by tropical disturbances which are found to the north of the ITCZ and range from easterly waves, through tropical depressions, to full hurricanes. It is these synoptic scale features and the influence of the ITCZ which account for most of the rainfall of the rainy season.

Seasons

The four seasons of the temperate lands have no meaning in tropical latitudes. Rainfall must here be the criterion for dividing the year into seasons. In Barbados, the dry season is generally considered to last from December through May and the rainy season from June through November. The intensity and duration of the two seasons varies with respect to situation. For example, a station such as Lion Castle in the higher part of the island will have a longer and more intense rainy season than a station such as River Plantation in the lowlands of the south-east. Another point to bear in mind is that it is quite possible to experience a week of dry season weather in the "wet season" month of July and several consecutive wet days in the "dry season" month of April.

Available Climatic Records

Rainfall has always been of prime importance to the plantation owners of the island because on this mainly depends the quality and quantity of their sugar crop. It is not surprising, therefore, to find that rainfall data are available for approximately eighty stations, mainly plantation sites, some of which possess records dating back to the middle of the nineteenth century. But, whereas rainfall has been more than adequately covered by the network of amateur stations, other climatic parameters have received scant attention and the only station for which long-term averages of temperature, humidity, rainfall and sunshine are available is Codrington

Agricultural Station in St. Michael parish. A second full climatological station, Seawell International Airport, Christ Church, dates from the period of increased aviation activity at the close of the Second World War.

The Waterford Climatological Station

Such was the climatological coverage in 1958 when the Geography Department of McGill University undertood the task of establishing a climatological station at Waterford, St. Michael, a short distance beyond the north-eastern suburbs of Bridgetown. The aims of the station were to make meteorological and climatological measurements, especially on a micro scale, at a tropical station within the trade-wind zone, to undertake research on problems of agricultural meteorology on an island with an economy virtually dependent on the production of sugar cane, and to establish a centre from which research into more general aspects of Caribbean geography and climatology could be undertaken.

The station, which was established on five acres of leased land, came into being through co-operation between the Barbados Ministry of Agriculture, Lands and Fisheries, and McGill University. Although enjoying the benefit of having the Codrington Agricultural Station data as a long-term comparison, it seems, nevertheless, a little unfortunate that the station should have been located in an area covered by an existing climatological station when so little is known of conditions in other parts of the island. Dr. Ivan Smith, a native Barbadian, was Director of the station until his departure for Ghana in 1962. By this time the Waterford enterprise had become a section of the Bellairs Research Institute, St. James, under the director-

TABLE ONE

Means* of 1959-1966 Data for Waterford, St. Michael

	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Mean Temperature (^{o}F)	76.4	76.2	77.4	78.5	79.9	80.7	80.1	80.2	79.5	79.1	78.5	77.3	78.6
Mean Daily Max.	83.8	84.2	85.5	86.4	87.2	86.9	86.1	86.9	86.8	85.9	85.7	83.9	-
Mean Daily Min.	68.9	68.1	69.3	70.5	72.6	74.3	74.4	73.5	72.3	72.2	71.3	69.5	-
Mean Extreme Max.	85.7	86.3	87.3	88.1	88.9	88.9	87.9	88.8	88.9	88.1	87.5	86.3	89.6
Mean Extreme Min.	62.7	61.8	63.1	66.0	68.0	70.0	70.0	69.1	68.1	68.4	67.0	63.2	60.6
Mean Extreme Grass Min.	56.6	55.6	57.1	59.0	61.2	63.3	64.4	63.0	62.7	62.7	61.4	57.3	54.7
Total Rainfall (Ins)	2.12	1.58	1.19	2.03	1.51	3.83	6.82	3.78	5.84	6.37	3.19	3.70	42.70
Most Rain in 24 hours	0.56	0.53	0.25	0.77	0.54	0.98	2.03	0.99	1.62	1.91	0.96	1.23	2.96
Number of Rain Days	19	17	14	15	13	19	24	22	20	21	17	17	218

* 6-8 year means.

ship of Dr. John Lewis. From July 1963 to June 1965 the author was in charge at Waterford, during which time the work at Waterford was continued and fourteen other micro-climatological stations were set up at various sites on the island, at eight of which daily total solar radiation on a horizontal surface was recorded and at all fourteen weekly evaporation measurements were obtained. Since January 1966 Professor B. J. Garnier has been in charge of the research programme on Barbados and a complete re-organization of the Waterford Station was started in the summer of 1966.

The chief results of the work conducted at Waterford from 1958-66 have been the series of means given in Table One, and two studies based on the evaporation and evapotranspiration measurements made at the station (Rouse and Watts, 1966). In the following section these means and the general results of the radiation study will be incorporated into a description of the main features of the climate of Barbados.

The Elements of Climate

(a) Temperature

Temperatures do not vary to any appreciable extent over the island either from month to month or from site to site. Mean temperatures at Waterford range from 76.2° in February to 80.7°F in June, the highest temperatures being recorded just before the onset of the rainy season. The mean annual temperature is 78.6°F and this has only varied between 78.4°F and 78.7°F in six years of record. The diurnal range of temperature in each month is much greater than the annual range. Mean daily maxima vary between 83.8°F in January and 87.2°F in May. Mean daily minima range

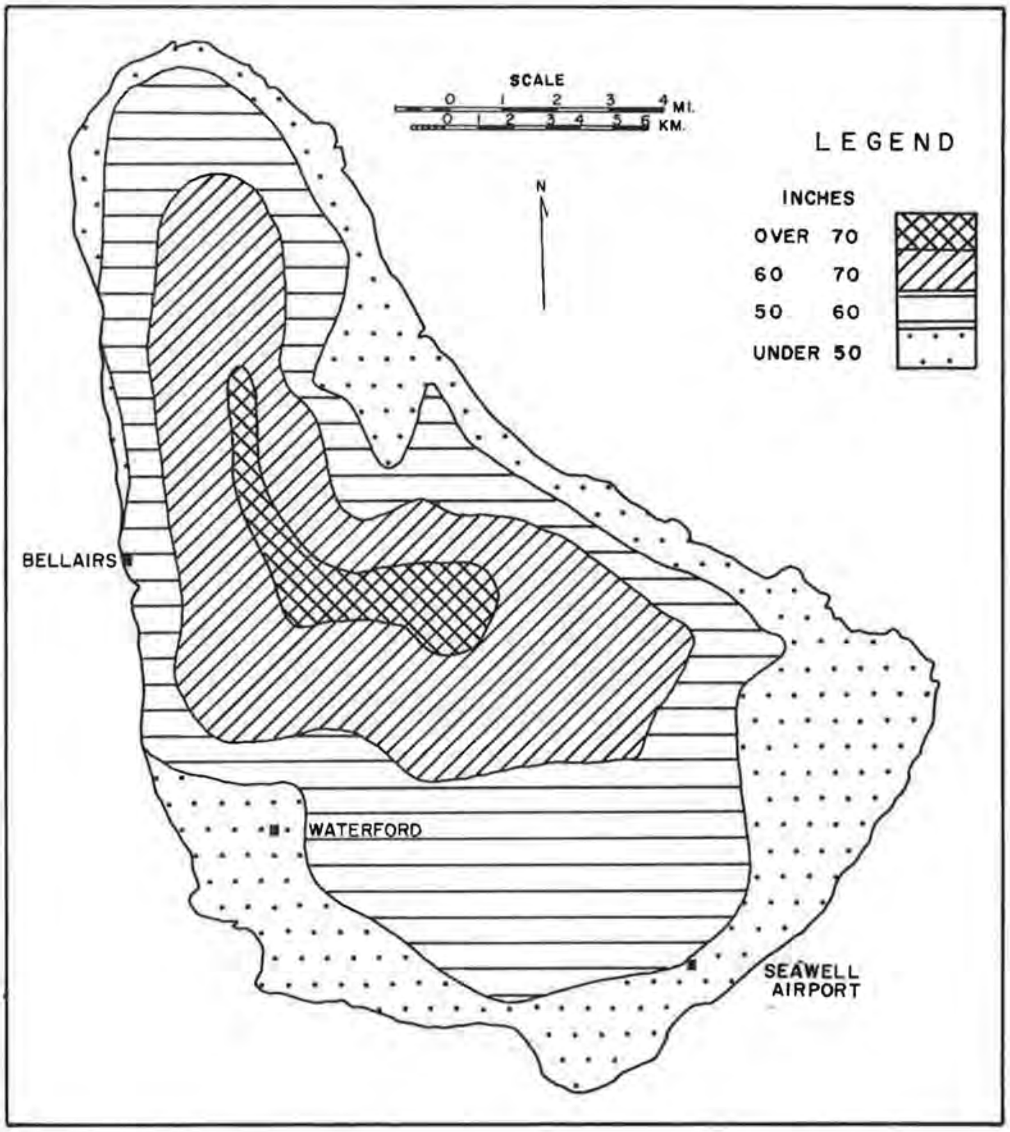


Fig. 2. The Mean Annual Rainfall of Barbados (adapted from a map by Wayne Rouse).

from $68.1^{o}F$ in February to $74.4^{o}F$ in July. The extreme maximum temperature during the period of record is $90.5^{o}F$ and the extreme minimum $59.0^{o}F$. Grass minima may fall to the mid or even low 50's during the early months of the year, there having been a record low of $52.8^{o}F$ in December, 1964. Prolonged "cool" spells with temperatures noticeably below average, such as was experienced during December 1964, are, however, a very rare feature of the climate. Depressions over the North Atlantic taking a more southerly course than usual and giving spells of persistant northerly or north-easterly winds to the southern Caribbean account for these rare weather episodes. During the period mentioned above a relict cold front which was, in fact, traceable at least to the north coast of Guyana, was observed to pass southwards over Barbados bringing northerly winds to the area.

(b) Rainfall

Unlike temperature, rainfall varies considerably in different parts of the island. The south-east, north-east and south-west are the driest areas, while the central and northern upland areas receive the most precipitation (Fig. 2). Annual totals vary from over 80 inches in the wetter areas to under 50 inches in the drier parts. At Waterford, with a mean annual total of 42.70 inches, monthly rainfall is usually less than 2.25 inches from January through May and above that figure during the remaining months of the year. Monthly and annual totals vary considerably from year to year, especially in the drier area. In July, 1963, 12.98 inches of rainfall were recorded at Waterford while July, 1959, produced only 2.71 inches. Similarly, December rainfall has varied from 8.84 inches to 1.30 inches. The very high totals are usually the result of one or two exceptionally heavy storms. In July 1963, a total of 6.89 inches was recorded in one twenty-four hour period, representing over 50% of the month's rainfall. This heavy fall is especially remarkable since it was not associated with a hurricane. Annual totals of rainfall at Waterford have ranged from 36.18 inches (1960) to 52.05 inches (1963). Although rainfall totals vary considerably the number of rainy days remains remarkably constant, ranging between 207 and 227 in a six year period. Even in the dry season one day in two is a rainy day.

Thunderstorms occur only rarely and mostly during periods of disturbed rainy season weather. The occurrence of hail on the island was reported for the first time in 1964.

(c) Cloudiness and Sunshine

Cloudless skies are extremely rare in Barbados. Usually the sky is two to six-eighths covered with cloud, the higher values being in the rainy season. Conditions of complete overcast, however, are infrequently experienced. Convection type clouds predominate over all other types at all times of the year. These clouds range from the small cumulus humilis to the giant cumulo-nimbus characteristic of more disturbed types of weather. The early morning tends to be fairly clear but the cumulus clouds soon build up over the higher areas and spread to the lowlands. The nights are less cloudy, but convection clouds are nevertheless still visible in the sky at this time. Cumulus clouds have a tendency to line up in "streets" parallel to the prevailing wind with clear areas representing the down-draughts between. Bad weather stratus and nimbostratus clouds are infrequent and occur only during periods of synoptic disturbances.

Exact data on hours of bright sunshine are difficult to obtain because the tropical sun strongly burns the sensitized sunshine card and the burn often continues into subsequent periods of no sunshine when cumulus clouds cross the sun. A record of one hour's sunshine may thus really represent only fifty minutes of actual bright sunshine. Figures for Codrington Agricultural Station and Seawell Airport give annual totals slightly in excess of 3,000 hours, with little variation from year to year. In a normal year January has the highest percentage of possible sunshine and September the lowest. McIntosh (1934) thought sunshine totals in the upland area would be similar to those of the lowlands, but the radiation results presented below show that this is most unlikely.

(d) Wind

Wind direction over the whole island is predominantly from an easterly point. Only during the rainy season will the wind veer more to the south. Northerly winds may blow for short periods during an unusual spell of weather, as in December 1964. When centres of low pressure are in the area the wind may blow from any point of the compass depending on the position of the storm in relation to the island. Thus, a hurricane passing to the north of Barbados will give westerly winds to the island.

Wind speed is strongest, except for occasional hurricanes, during the dry season when the Trades are firmly established and lightest during the rainy season when Barbados occasionally comes under the influence of the doldrum belt (ITCZ) of light winds. At the latter time of year sea-breezes may become established on the west coast during the late morning.

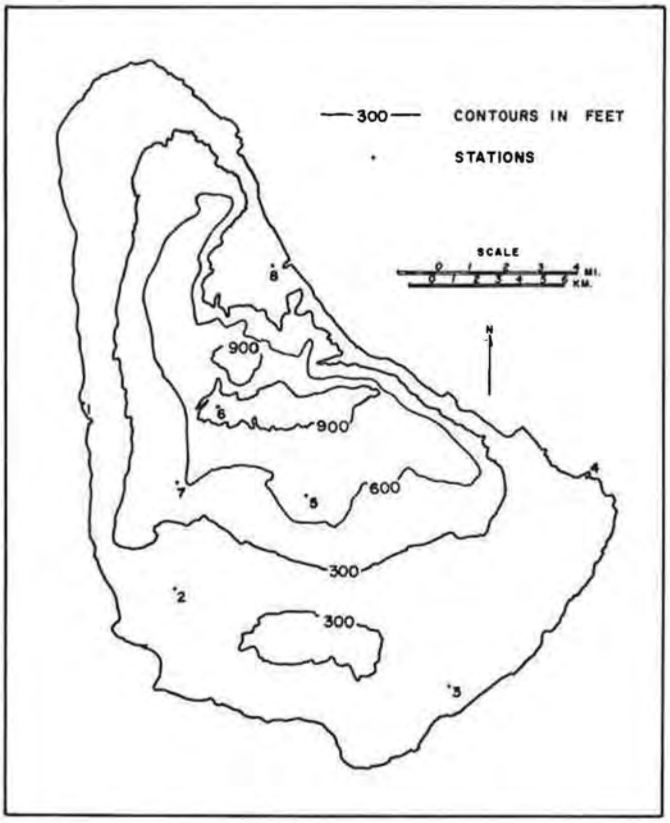


Fig. 3. Radiation Stations, Barbados
(Numbers as in Table Two).

Fig. 4. Housing for Silicon Cell and Meter.

(e) Solar Radiation

Prior to the author's own studies, radiation records of a broken nature were available for only two stations on the island: (a) the Brace Experiment Station where records were kept only during periods of experimentation with solar cooking devices; and (b) the Waterford Climatological Station where the pyranometer was situated on the roof of the nearby Combermere School and suffered from an almost total disregard of the frequent re-calibration needed for such an instrument.

Table Two gives details of the eight solar radiation stations which were in operation for varying periods between August 1st, 1964 and May 31st, 1965.

The positions of the various stations are shown on Fig. 3. The sites were chosen in an attempt to cover all sections of the island, from the cloudy, rainy airea largely above 900 feet (represented by Mt. Misery, 1070 feet) which has a mean annual rainfall of 72-78 inches through the intermediate areas (Groves Agricultural Station, 790 feet, 65-71 inches mean annual rainfall), to the less cloudy, drier areas of the south-east (Seawell Aiport, 170 feet, 40-50 inches mean annual rainfall). Brace Experiment Station represented a west coast location and Ragged Point Lighthouse fulfilled a similar role on the east coast.

Instrumentation consisted of silicon-cell ampere-hour meter combinations housed in a specially-built box (Fig. 4). The instruments were calibrated at the Brace Experiment Station before being taken out into the field. Early calibration results and a description of the instrument are to be found in Whillier and Tout (1965). Problems of organization were many in a study of this nature, which attempted to obtain daily values of total solar radiation on a horizontal surface from eight reporting stations, but nevertheless a considerable volume of reliable data was obtained.

As expected, the areas with highest values of mean daily radiation were found to lie in the south-eastern parts of the island. Little difference was noted in radiation received at Ragged Point, directly on the east coast, and at Seawell Airport, a little way inland from the south-east coast. In October, 1964, for example, Ragged Point had a mean value of 442 langleys daily whereas Seawell recorded 458 langleys, while in April 1965, the mean daily figure at Ragged Pt. was 590 langleys and at Seawell 584 langleys. A consideration of the areal cloud patterns will throw light on the reasons why radiation values vary widely over the island. In the region of Rugged Point clouds tend to form over the upland areas to the west and the coast itself remains comparatively clear. Similarly at Seawell Airport clouds are frequently seen over the uplands to the north while the lowlands of the south-east are much more free of cloud. By contrast the radiation record at Walkers, commenced on March 4, 1965, indicates that radiation values were lower than those in the south-east. In April, 1965, for example, the mean daily value at Walkers was 528 langleys, as opposed to the figures already given for Seawell and Ragged Point. Cloud building up over the Scotland District to the west would probably account for these lower values. An indication of the radiation range on the island is given by the figures in Table Three.

TABLE TWO

Details of Solar Radiation Station Network

	Parish	Altitude in Feet	Rainfall Area* (in ins.)	Operated by:	Solar Radiation Station No.	Beginning of Record**
Brace Experiment Station	St. James	Coast	51-57	D. G. Tout	51	Aug. 1, 1964
Waterford	St. Michael	130	40-50	V. Gibbs) D. G. Tout)	52	Sept. 9, 1964
Seawell Airport	Christ Church	170	40-50	Met. Office Staff	53	Aug. 28, 1964
Ragged Pt. Lighthouse	St. Philip	120	40-50	Mr. Wilson	54	Sept. 3, 1964
Groves Agric. Station	St. George	790	65-71	Mr. Walker	55	Aug. 29, 1964
Mt. Misery	St. Thomas	1,070	72-78	Mr. Francis	56	Dec. 12, 1964
Edge Hill	St. Thomas	480	58-64	Mr. Hudson	57	Feb. 20, 1965
Walkers	St. Andrew	240	40-50	Mr. Grant	58	Mar. 4, 1965

* Taken from the map of mean annual rainfall in Rouse (1962) but with amended lowest category.

** Records closed on May 31, 1965, except for Seawell Airport whose record terminated on May 13.

TABLE THREE

Mean Total Solar Radiation in Langleys,
May - June, 1965

	May, 1965	June, 1965
Ragged Pt.	578	578
Groves	430	450
Mt. Misery	474	473

Other Features of the Climate

(a) Hurricanes

In most years Barbados lies to the south of the main hurricane tracks but, on average, about once in 50 years a hurricane will pass over the island. The last one, "Janet", in September, 1955, was the first recorded during the twentieth century. Any hurricane in the vicinity, however, will affect the weather on Barbados, giving increased cloudiness and rainfall. This was well seen at the end of September, 1963, when hurricane "Edith" moving to the north and hurricane "Flora" passing to the south brought inclement weather to the island within the space of a few days.

(b) Sea Surges

During the northern winter heavy seas are occasionally experienced on the shores of Barbados. These are the result of storms in the North Atlantic taking a southerly course and the northerly winds in the rear portion of the storm creating a sea surge which sweeps into the eastern Caribbean. The local weather remains fine during these surges.

Summary

The most meaningful division of the climatic year in Barbados is in terms of a rainy season and a dry season, the intensity and duration of which depends on location within the island. Temperature differences are small from month to month and from region to region although diurnal ranges may reach 20 F° on occasion. Radiation, cloudiness and sunshine, however, vary with location. The upland areas stand out as relatively more cloudy and rainy than the lowlands. But everywhere, even in the rainy season, the accent is on quiet, sunny, weather occasionally disturbed by a brief, but intense, rainshower. The passage of a disturbance approaching hurricane strength is very much the exception rather than the rule.

Acknowledgements

Sincere thanks are extended to Professors Lloyd, Garnier and Hills who made it possible for the author to experience the climate of Barbados at first hand, and to those named in Table Two who willingly helped maintain the network of radiation stations.

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RECENT DEVELOPMENTS IN THE McGILL UNIVERSITY CLIMATOLOGY PROGRAMME IN BARBADOS

by

B. J. Garnier*

The re-organisation of the observing site at Waterford, Barbados (fig. 1) referred to in the preceding article of this Bulletin, has been made primarily in order to integrate the work in Barbados more closely with the overall programme in climatology within the Department of Geography at McGill University itself. The latter programme is currently concentrating on microclimatology (Garnier, 1967). One of its principal aims is to use the field stations at (a) Knob Lake, Schefferville, (b) Mont Ste. Hilaire, Quebec, and (c) Waterford, Barbados, as laboratories for examining the role of the surface in the total energy and moisture budgets under differing atmospheric states in different climatic regions. This involves measuring the inter-connection between such physical parameters as slope, aspect, soil properties, and vegetation on the one hand, and energy fluxes and prevailing atmospheric circumstances on the other, with a view to establishing models whereby the two may be linked.

A first step in such a programme is to measure the radiation and energy balances at selected locations and to map their topographic variations

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Fig. 1. Re-organising the site at Waterford, Barbados.

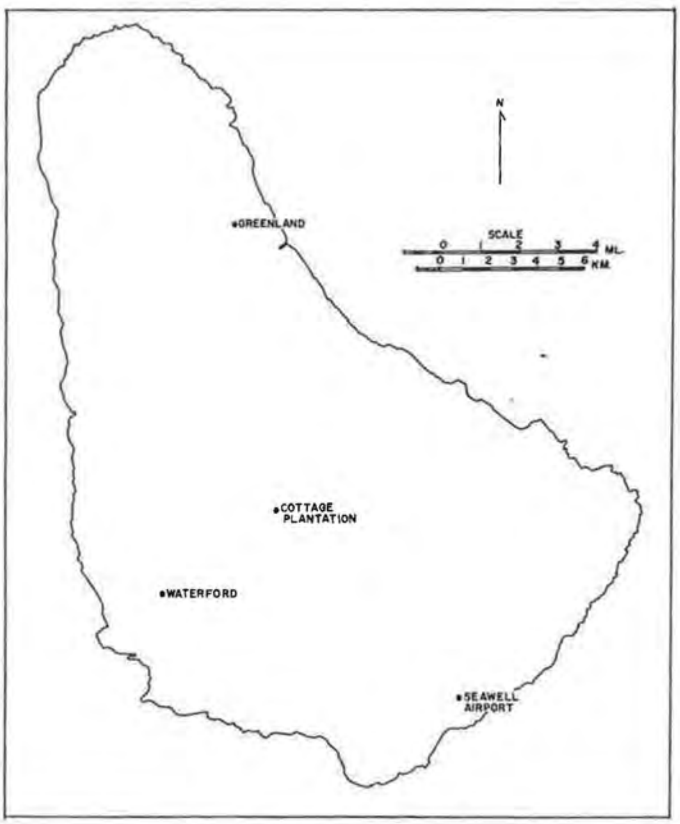

Fig. 2. Location of Observing Stations for Energy Budget Measurements.

by reference to the character of the surface geometry.* It is on work of this nature that the programme in Barbados will concentrate in the immediate future.

With this aim in view, the instrumentation at Waterford has been improved to enable the necessary energy parameters to be measured and three new stations are being added to the observation network to be used during a period of intensive observations planned to start in July 1968, and to last about eighteen months. The three new stations are at Seawell International Airport (in co-operation with the Barbados Meteorological Service), at Greenlands and on Cottage Plantation (Fig. 2). Observations from these sites, in conjunction with those from Waterford, will make it possible to sample the contrasts between the regions of windward (east) and leeward (west) exposure, and between the coast and the interior. Since each site will consist of generally similar grassed plots they will permit direct comparison of energy budget variations between sites differing only in location, aspect, and elevation.

Standard methods will be used to measure the various parameters of the energy budget. Net radiation, for example, will be measured by battery-operated net radiometers.

A battery-operated recording system will also be used to measure heat fluxes in the ground at Waterford, and a similar instrument will be used

* A brief reference to the formulae and procedures involved in this will be found elsewhere in this Bulletin (Ohmura, 1968). More substantive accounts are currently being prepared for publication elsewhere.

in succession at the other three sites. At the latter there will also be soilheat flow plates read at hourly intervals during periods of especially detailed observations and twice-daily at other times. Continuous records of ground temperature will be made by mercury in steel recording thermometers inserted one centimetre below the ground surface, while temperature and humidity profiles above ground will be measured by shielded wet and dry thermocouples using battery-operated recorders.

The general organisation of the programme will be such as to provide short periods of intensive study against a background of continuing routine observations. Thus, each station will also be equipped with the standard instruments for measuring wet and dry bulb temperatures, wind speed, evaporation, and rainfall. At each station there will also be a bi-metallic recording actinograph. This arrangement will not only enable the different climatic seasons to be sampled in detail, but will also provide a means for examining the efficacy of using the records from standard instruments read once, or at most twice, daily for estimating the heat budget in the context of a tropical island in a humid, trade-wind environment.

The value of a programme of this nature will be greatly increased by the fact that it will coincide with a period of detailed surface/air energy studies being organized by Professor Garstang of Florida Station University during the summer of 1968 and 1969.* The particular programme described in this short article, therefore, will contribute towards the concerted

* An account of this programme, together with more information on the McGill contribution, is expected to appear shortly in the Bulletin of the American Meteorological Society.

efforts which will soon be made in Barbados to understand the interface characteristics of a small island of varied slopes, surfaces, and aspects within the moist trade wind air stream. By approaching the matter geographically in terms of the varying inter-connections between the land and the air under different atmospheric states, it is hoped that current developments in the McGill University programme of climatology in Barbados will help to achieve a better understanding of the response of different parts of the island to the large-scale, steady-state attack of trade wind conditions, or to the influx of meso-scale synoptic disturbances, or to contrasting solar energy situations. Such knowledge may then be put to work to evaluate conditions not only in other parts of the Caribbean, but also elsewhere. It may thus be possible to estimate the microclimatology of other tropical islands by a knowledge of surface character and prevailing atmospheric conditions. Such an achievement will be valuable both scientifically and as a contribution towards a better understand of environmental characteristics important to the economic development of many parts of the underdeveloped world.

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MEASUREMENTS OF AERIAL SALT ON THE COAST OF BARBADOS

by

R. E. Randall*

During the period May to September, 1967, and again in December, 1967, a study was made of the coastal environments and vegetation of Barbados. Part of the environmental research included the measurement of aerial salt particles since these were thought to be a major factor in the distribution of vegetation. The importance of salt and the response to it by plants are described by Boyce (1954).

Apparatus

In order to measure the aerial salt ten instruments, modified from the design of Hudson (1963), were constructed. Each was composed of a stand (which was, in fact, an evaporimeter box), from which projected a square piece of 'Glasslite' measuring 2 ft by 2 ft, and held firm against the wind at its outer edge by a cord joined to a weight on the ground (Fig. 1(a)). This acted as a protection from rain but was not large enough to cause serious wind interference. Under the 'Glasslite', and also connected to the stand, was a wooden supporting strip into which two hooks were screwed. A piece of washed towelling, one foot square,

* R. E. Randall is a graduate of Cambridge University currently carrying out research at McGill University prior to returning to Cambridge for doctoral studies in October, 1968.

(a)

(b)

Fig. 1. Aerial Salt Measurement Techniques
(a) Type of Instrument;
(b) Line-up of Instruments.

with tabs at each corner, was suspended from these hooks and weighted at the bottom by a piece of wood also containing two hooks.

The amount of salt present on exposed towels was discovered by placing them separately in jars containing 300 ccs of distilled water and pummelling thoroughly to force out the salt particles. The solution was then measured on a Lock Conductivity Bridge and the result recorded in micromhos* per centimetre.

Method

The instruments were used by devising three circuits, each covering approximately one-third of the island's coasts, and each including selected windward and leeward points. At each point two or more instruments were set up (Table 1) with the towelling positioned to face squarely into the prevailing trade wind. The instruments were placed in line as shown in fig. 1(b). They were located at a known distance from the coast in order to measure the change in salt content with distance from the sea. The first circuit covered the northern part of the island, the second included the central part both east and west while the third was along the south coast (Fig. 2). Circuits two and three included a central station inland at Edgehill. Towels were replaced every 24 or 48 hours. The replacement was made at the same time for each station and took place between 4.30 p.m. and 5.30 p.m. when the wind speed tends to be lower than during the day. On each circuit readings were taken for more than one week and a variety of weather conditions were included. During the

* One micromho is the conductance of a body having a resistance of one micro-ohm.

TABLE 1

Location of Aerial Salinity Instruments

	Gauge No.	Distance From Sea (feet)	Distance Above Sea (feet)
Circuit 1			
River Bay	1	10	1
	2	65	54
	3	30	1
Animal Flower Bay	4	900	78
	5	500	61
	6	110	58
Maycocks Bay	7	35	7
	8	130	9
Holetown Beach	9	72	1
	10	12	2
Circuit 2			
Bottom Bay	1	50	7
	2	190	-3
	3	255	25
	4	475	31
Brighton Beach	5	12	3
	6	78	5
Belleplaine	7	315	20
	8	495	7
	9	750	10
Edgehill	10	INLAND	
Circuit 3			
Chancery Lane	1	42	6
	3	260	6
	9	148	9
Rockley Beach	5	3	2
	6	90	2
Foul Bay	7	135	-5
	8	35	2
Edgehill	10	INLAND	

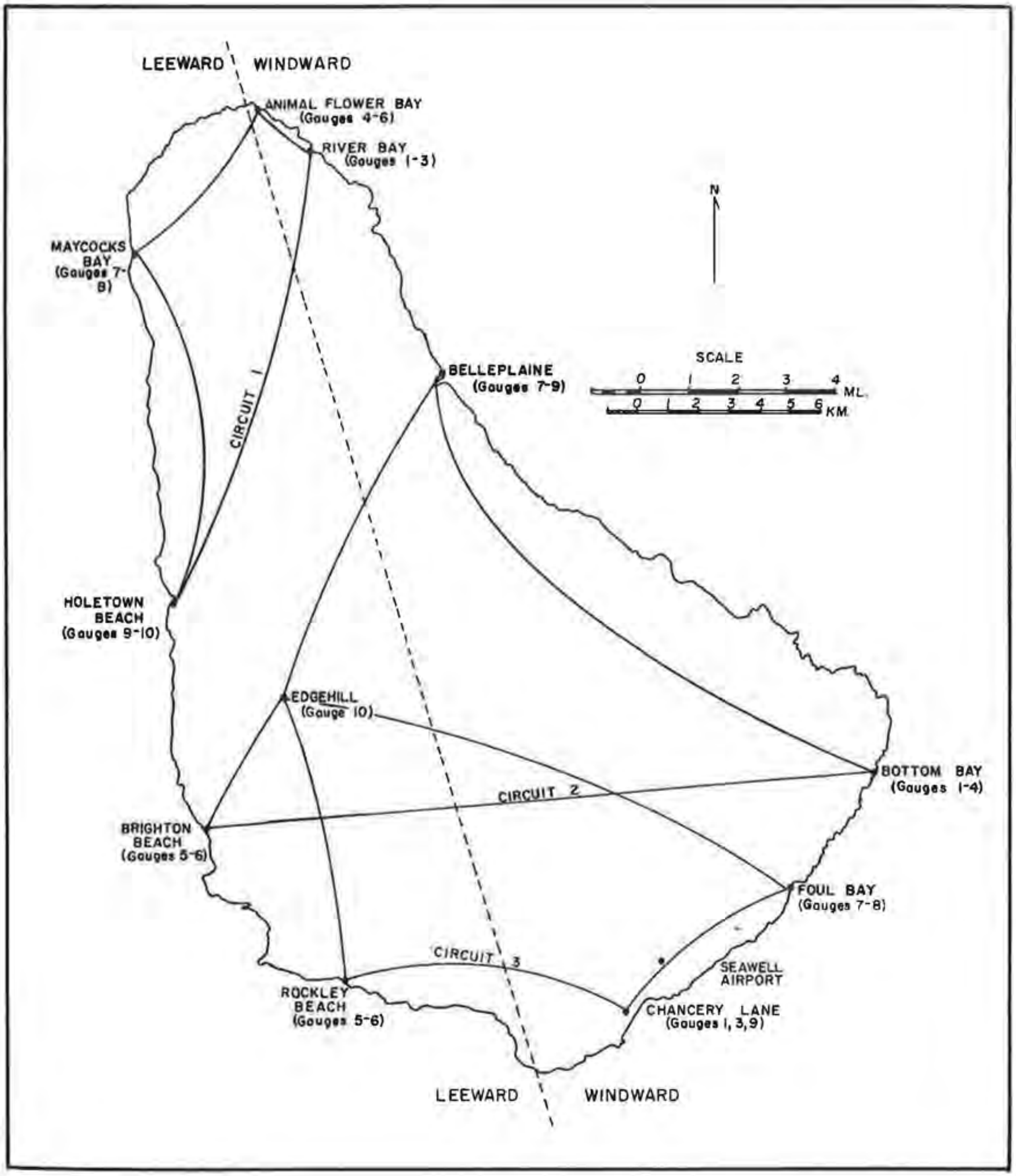


Fig. 2. Location of Aerial Salt Observation Stations and Circuits in Barbados.

time when records were being taken, windspeeds from the anemometer at Seawell Airport were calculated for the same 24 and 48 hour periods. This anemometer is situated at 10 meters above ground level and is thus free from ground interference. Also, each day during the experiment the amplitude of the ocean waves in relation to the wind speed was noted.

Results

The results of this work are given in Tables Two to Seven, which appear at the end of this article. In most cases there is a decrease in salinity with increase in distance from the sea, suggesting that the ground surface acts as a roughness parameter causing a decrease in windspeed and a consequent loss of airborne salt particles. This relationship does not hold true for Bottom Bay, Circuit Two, however, where excessively low readings are recorded for gauge No. 2. This is because the gauge is situated in a protected pocket at the foot of a cliff behind a dune. It will be seen that on the leeward coast, as illustrated by the values for Brighton, Holetown, Maycocks and Rockley, the salt levels are considerably lower than to windward, and the fall-off rate is much less. This shows that the major source of salt particles is from the trade winds which blow from the windward side of the island, and not from the adjacent waves. This point is further emphasized by the small difference in salt levels between Edgehill in the centre of the island and the gauges on the leeward coast. However, at all stations on the leeward coast locally derived salt is just enough to give a higher reading at the seaward gauge. At certain times, particularly during winds associated with hurricane disturbances such as Beulah in September, 1967, and also during storm swells such as in late November and early December, 1967, the leeward coast may receive large amounts of locally derived salt particles which have considerable effect upon the vegetation and mask the importance of the trade winds.

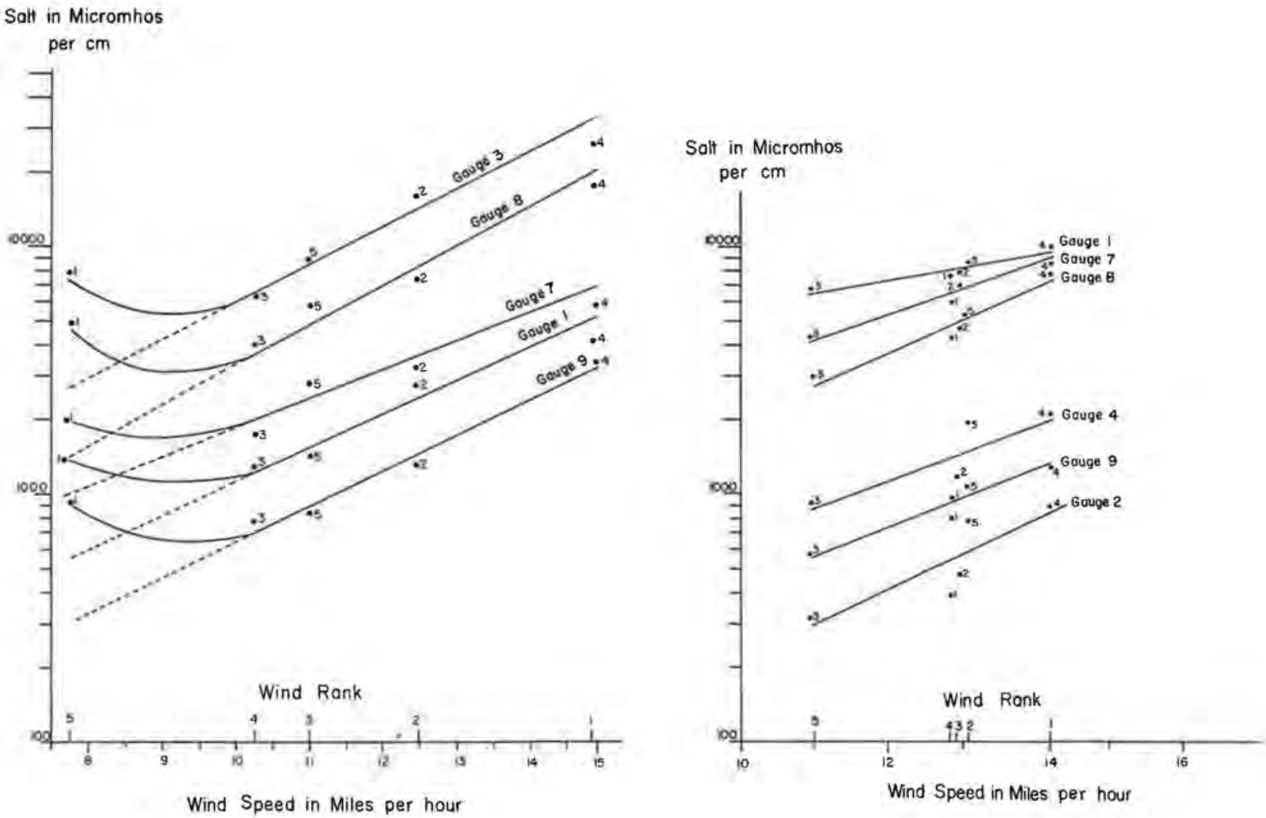
A second noteworthy factor is that there is an extremely close relationship between change in windspeed and change in salt deposition at any one location. If the ranked windspeeds are correlated with the ranked salt quantities, they are seen to be in a similar order. This relationship does not, however, apply to the leeward coast stations since there are so many interference factors that the true windspeed at each station and the windspeed at Seawell are not comparable. Also there are particular anomalies that occur throughout the windward coast stations. The records from Chancery Lane and Foul Bay on 12 - 14 July, 1967, constitute a good example. At these two points a much higher salt reading is found than would be expected by examining the windspeeds (Fig. 3). However, during those two days the wind only blew from the trade quadrants 62% of the time, the rest coming from the southerly quadrant, thereby giving higher salt readings on the south coast despite the lower windspeeds. Likewise over the same period readings from gauges 5 and 6 at Rockley, also on the south coast but to leeward, were relatively high.

For a similar reason the readings at River Bay and Animal Flower Bay (Circuit One) were particularly low during the period June 14 - 17 inclusive. At this time much of the wind was blowing from a south-easterly direction. The masking effect of wave amplitude is illustrated over the period June 11 - 13 (Circuit One), when seas began to rise as the wind died down. This resulted in much higher salt figures on June 13 than June 9 when the sea was low despite the higher windspeed on the latter date. It will be seen from a graph of windspeeds and windward-coast salt measurements for Circuit two (Fig. 3), that when the wind is always from the same direction and when the wave amplitude is not at variance with the windspeed there is a log relationship between windspeed and salt deposition. The general reliability of these figures is also shown in Fig. 3. Collection period 5 at each gauge gives results higher than expected. This coincides with high seas on July 3 - 5. Conversely, all figures from collection period 1 are lower than expected and coincide with low seas on June 21 - 23.

It is suggested that in further experiments of this type it might be more useful to devise an instrument in which the towel is exposed in all directions. This could be achieved by wrapping the towel around a tin through which a pole could be passed. This pole would then be fixed in the ground and have a protective screen fixed horizontally to the top. Changes of the towelling could be easily effected by removing the screen and lifting off the tin. In this way readings closer to reality would be obtained whatever the wind direction.

Acknowledgements

I would like to thank Colin Hudson, the staff of Seawell Airport Meteorological Office, and the Sugar Producers Agronomy Research Unit



(a) (b)

Fig. 3. Relationship between Wind Speed and Salt Deposition in Barbados.
(a) Circuit Three; (b) Circuit Two.

(Barbados) for help of various kinds in undertaking this research. The research itself was financed under a scholarship from the North Atlantic Treaty Organisation (NATO).

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TABLE 2

Air Salinity, 1 ft squares, June 9 - 17, 1967

(in micromhos per cm - in solution of 300 cc's H_2O)

	RIVER BAY			ANIMAL FLOWER BAY			MAYCOCKS BAY		HOLETOWN BAY	
Date	1	2	3	4	5	6	7	8	9	10
9	3713	3102	1551	498	1175	4653	204	193	146	174
10	1344	1109	582	291	658	2491	169	159	160	197
11	2444	1974	1316	517	940	3478	183	150	131	150
12	6110	4600	2444	743	2444	11186	202	130	95	134
13	5546	4136	2068	568	2350	7332	141	117	80	128
14	1715	1580	709	282	696	2491	157	129	113	120
15	799	465	385	212	273	1029	131	81	91	103
16	259	207	202	124	139	282	122	65	70	75
17	437	265	204	124	183	583	115	113	125	126
Daily Avge.	2485	1938	1051	373	984	3725	158	126	112	134

TABLE 3

Air Salinity, 1 ft squares, June 21 - July 5, 1967

(in micromhos per cm - in solution of 300 cc's H_2O)

	BOTTOM BAY			BRIGHTON BEACH			BELLEPLAINE			EDGEHILL
Date	1	2	3	4	5	6	7	8	9	10
21/23	7708	395	2786	961	-	136	6005	4290	808	150
24/26	8178	479	3431	1175	113	136	6900	4700	-	160
26/28	6862	325	-	921	315	-	4136	3008	569	164
28/30	9776	873	-	2068	221	268	8570	7614	1301	240
3/5	8460	790	4275	1927	-	508	-	5170	1097	-
Daily Avge.	4098	286	1915	705	108	131	3201	2478	401	89

TABLE 4

Air Salinity, 1 ft squares, July 12 - 30, 1967
(in micromhos per cm - in solution of 300 cc's H_2O)

	CHANCERY LANE			ROCKLEY BEACH		FOUL BAY		EDGEHILL
Date	1	3	9	5	6	7	8	10
12/14	1363	7614	912	508	249	1974	4888	249
14/16	2773	15745	1326	306	228	3431	7332	308
16/18	1287	6486	761	202	124	1786	3901	-
18/20	4089	26380	3290	348	263	5557	17426	235
28/30	1410	8554	846	508	268	2773	5625	114
Daily Avge.	1092	6378	714	187	113	1552	3917	113

TABLE 5

Winds at Seawell Airport during Salinity Measurements
Circuit 1, June 8 - 17, 1967

Date	Wind Speed	Rank	Percent from Trade Quadrants	Wave Amplitude in relation to Wind Speed
8/9	12.92	2	100	L
9/10	9.08	5	100	M
10/11	8.92	6	92	H
11/12	14.50	1	100	L
12/13	12.63	3	100	M
13/14	9.21	4	100	H
14/15	7.42	7	83	M
15/16	4.71	9	50	M
16/17	6.04	8	92	H

TABLE 6

Winds at Seawell Airport during Salinity Measurements
Circuit 2, June 21 - July 5, 1967

Date	Wind Speed	Rank	Percent from Trade Quadrants	Wave Amplitude in relation to Wind Speed
21/23	12.85	4	100	L
24/26	12.93	3	100	M
26/28	10.95	5	100	M
28/30	14.20	1	100	H
3/5	13.08	2	100	M

TABLE 7

Winds at Seawell Airport during Salinity Measurements
Circuit 3, July 12 - 30, 1967

Date	Wind Speed	Rank	Percent from Trade Quadrants	Wave Amplitude in relation to Wind Speed
12/14	7.72	5	62	L
14/16	12.45	2	100	M
16/18	10.27	4	100	M
18/20	14.91	1	100	L
28/30	11.00	3	100	M

SOME RESULTS OF A PILOT STUDY OF THE URBAN CLIMATE IN MONTREAL

by

Tim R. Oke*

In comparison with other surfaces, the city has received very little attention in climatology. Previous studies have been concerned with the effects of the city and its environment upon individual climatic elements. The influence of the city in attenuating solar radiation and increasing air temperature has attracted the most interest.

The changes in these climatic elements brought about by the city's surface character, are really a reflection of changes in the radiation and energy balances associated with an urban environment. The relative magnitude of the components comprising these balances has not yet been explored (Munn, 1965). Similarly the vertical extent of the city's influence remains an area for research.

The programme of studies in urban climate now developing in the Department of Geography at McGill University, may be conveniently divided into two long-term projects:

1. energy balance studies - concerned with evaluating the relative magnitude of the component fluxes in the radiation and energy balances associated with urban surfaces; and
2. a study of Montreal's urban heat island - an attempt to combine

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both horizontal and vertical temperature measurements in a three-dimensional model of the heat island under different cloud, wind, and stability conditions.

The observational programme will include both helicopter soundings and automobile traverses. The former, which will be made in co-operation with Professor Conrad East of the University of Montreal, will make it possible to obtain temperatures at nine locations at a number of levels over Montreal. Automobile traverses are at present being undertaken as pilot investigations to discover some of the more important features of the Montreal heat island. This work will be used to help select the location of stations for later research.

The pilot investigations by means of automobile traverses are being carried out by a group of graduate and undergraduate honours students in geography as a class exercise in climatology.* The area of the city under study is broken down into sectors, each of which may be conveniently covered by an automobile in a two-hour period. All teams meet at a central location and then disperse and take readings throughout their assigned sectors. All teams re-assemble at the starting point at the end of the period. This procedure makes it possible to correct the results by a simple "error of closure technique" to offset the synoptic temperature change during the observation period. In this manner six teams can obtain in excess of 125

* Misses S. Boucher and K. Ott, Messrs. B. Banks, B. Basnayake, B. Fanta, P. Grevatt, A. Kirschen, F. Kousaie, S. Munro, M. Polansky, and D. Smith.

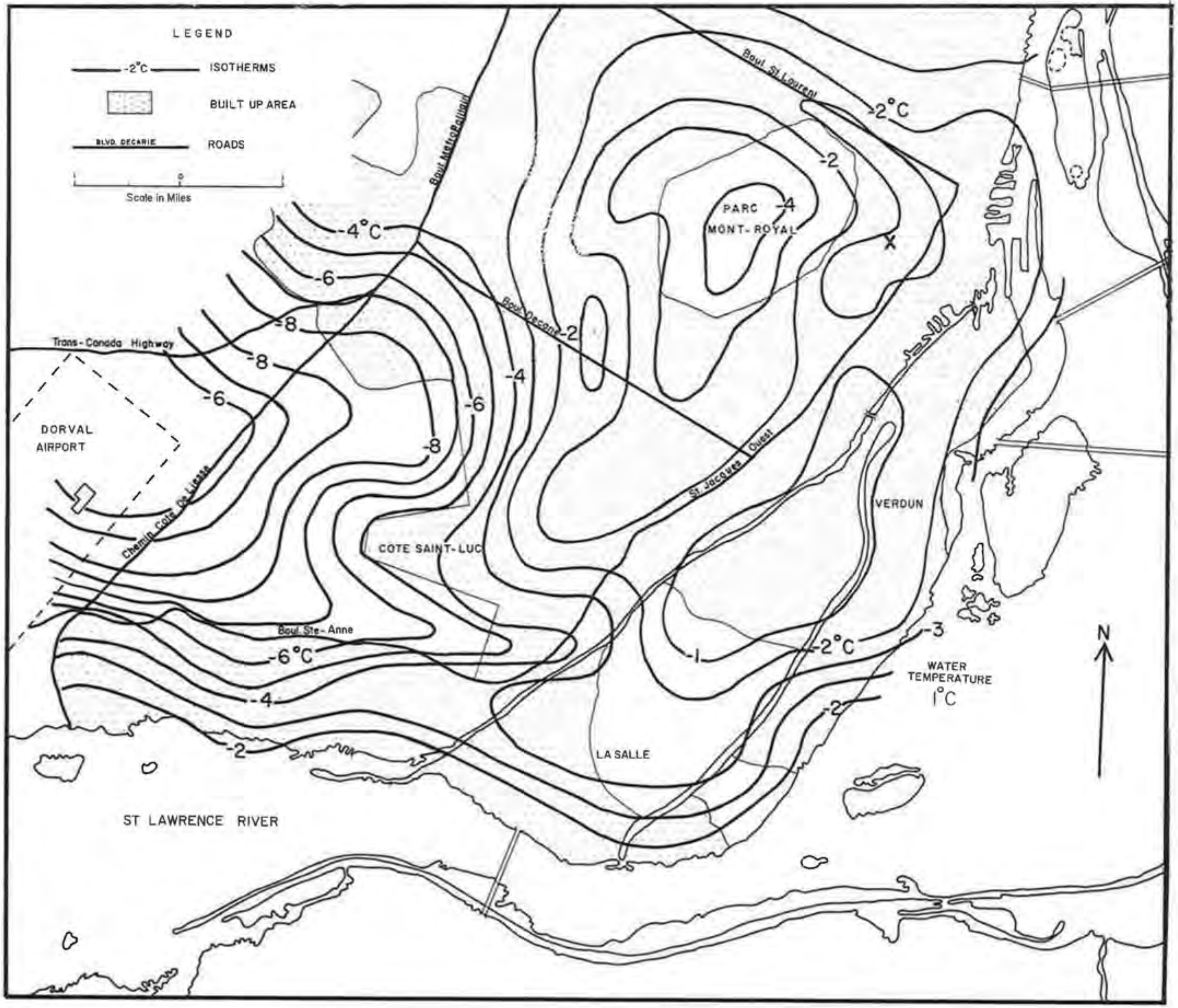

Fig. 1. The Distribution of Air Temperatures in Montreal on December 5, 1967, at 2100 hours E.S.T.

readings in a two-hour period.

Fig. 1 is an example of the results of one of these traverses. The isotherm map illustrates the spatial variation of temperature taken by means of Assmann psychrometers at a height of one metre above the surface in central and west Montreal at 2100 hours on December 5, 1967. The isotherms, which indicate an 8C^{o} (14F^{o}) rural/urban temperature difference, were drawn by interpolation from 143 point readings. The day of the observation period was cold and clear with weak ventilation. The ground was covered with old snow and slush. During the observation period skies remained clear; winds were from the north-east at about 1.5 m sec^{-1}. According to the micrometeorological tower at the Botanical Gardens, the lowest 60 m was characterised by a weak inversion (+0.006C^{o} m^{-1}), and, therefore, weak stability (Ri = +0.02).

Four points of general interest emerge from Fig. 1.

(a) <u>The urban/rural boundary</u>. The correspondence between the isotherms and the limits of the built-up area in the west are very apparent (e.g. the -6C^{o} isotherm almost traces the urban outline). This leeward boundary of the heat island is almost cliff-like in gradient, similar to an effect noted by Chandler (1965). There is a 6C^{o} change in temperature in 1500m (11F^{o} in one mile) in the Côte Saint Luc area. This is a sharper gradient than is found at most major fronts and thus one could postulate the existence of thermally induced winds, similar in nature to sea breezes, blowing across the 'cliffs' of the urban heat island. Dorval Airport appears to produce a slight warming influence of about 2C^{o}. A similar observation was noted by Summers (1964), who felt it may be due to the runways releasing heat absorbed during the previous day.

(b) Saint Lawrence River. The surface of the river remained unfrozen during the observation period, at a temperature of about $1^{o}C$ (St. Lambert Dock). This relatively warm influence is brought out by the way the isotherms parallel the shoreline.

(c) Heat Island Core. The core area of the heat island was not as well defined on this occasion as it has been on some other surveys undertaken in the current series. Usually the core is centred on the downtown high-rise building complex, marked as X on Fig. 1. With the north-east wind on December 5, 1967, however, the core has become discontinuous and displaced south-westwards into Verdun, although an examination of the soiling index (COH) values at this time did not indicate that the pollution cover had also shifted into the same area. Further studies will be made in Verdun to see if the industrial development there gives rise to a secondary heat core.

(d) Mount Royal Park. Fig. 1 shows that adjacent to the core area there is a 'cold spot' associated with Mount Royal. This has been a marked feature of all the traverses to date. There are two reasons for this cooling. Firstly, the area is open and vegetated, and secondly, the park rises to 150m above the surrounding city. The use of potential temperature could eliminate this altitude effect.

Surveys of this type are continuing under different weather conditions. It is hoped that the area of observation will be extended with the development of automatic recorders for one or two automobiles.

Acknowledgements

Thanks are due to the Montreal Health Department and the Department of Transport, Meteorological Branch, for supplying the COH and micrometeorological tower data.

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THE COMPUTATION OF DIRECT INSOLATION ON A SLOPE

by

Atsumu Ohmura*

1. Introduction

The contribution of direct insolation is of great importance to the microclimatological study of the heat budget at the surface of the ground, mainly for two reasons. Firstly, among the terms of the heat budget equation, heat exchange by radiation yields a large value and direct insolation is of primary importance among the five terms which comprise the radiation term. Secondly, direct insolation is more liable to be influenced by the topographic features of the ground than the other terms. Therefore, in order to study the heat budget on the actual surface of the ground, the evaluation of direct insolation must be the first element to be considered.

Several studies of this kind have already been attempted, of which the works of Kondrat'yev (1965) and Lee (1963) are typical. The equation used by Kondrat'yev is only useful for the calculation of instantaneous values. To make the equation effective, consideration of variations in the relation between the direction of a slope and that of the sun must be added, and this is usually an enormous calculation. Lee (1963) used an equation devised by

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Okanoue to integrate direct insolation for a certain time period. However, the equation, unfortunately, does not take into account the existence of the atmosphere. Neither of these equations is, therefore, suitable for this study because the value wanted is the total for certain time periods under different atmospheric states. For this purpose an equation has been developed in which the transmissivity of the atmosphere is taken into account.

2. The Elements of the Equation

The instantaneous value of direct insolation on a slope can be expressed by

$$I_s = I_o p^m \cos(\vec{A} \wedge \vec{S}) \qquad (1)$$

where I_s is the instantaneous value of direct insolation on the slope,

$\vec{A}$ denotes a unit vector normal to the slope,

$\vec{S}$ is a unit vector expressing the direction of the sun,

$\wedge$ is a symbol denoting the angle between the two vectors,

I_o is the solar constant = 2.00 ly $\min^{-1}$ (Johnson, 1954),

p is the transmissivity of the atmosphere,

m is the optical airmass.

To make the equation practical for computation, it is necessary to express equation (1) as a function of time. The co-ordinate system which will best express $\vec{A}$ is the one which is located at the site in question with the three axes directed to zenith, south and east. A system suitable for the expression of $\vec{S}$ has the origin in the centre of the earth with three axes consisting of (a) the polar axis, (b) the axis of the direct line marking the junction of the meridian plane at solar noon and the equatorial plane, and (c) the axis which is normal to the previous two axes (fig. 1).

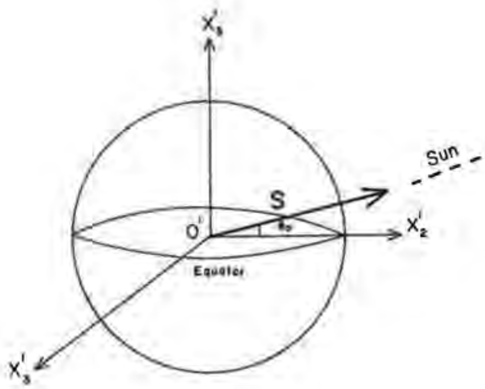

Fig. 1

We will call the first system the local system and the second system the global system. To complete the equation, the vectors must be discussed in a common system. It is mathematically equally possible either to transfer the local system into the global system or the global system into the local system. For the present purpose the latter procedure has been adopted, so that the local system is regarded as rotating once a day around the polar axis in the declination of $(90^\circ\text{-}f)$ where f is the latitude of the site.

The result of the transfer enables one to express the contents of the brackets in equation (1) as a function of the azimuth and gradient of a slope, the declination of the sun, the latitude of the site, and time. The equation takes the following form:

$$I_s = I_o p^{\left[1/(\cos f_o \cos f \sin w + \sin f_o \sin f)\right]} \Big\{(\sin a \sin b) \sin f \sin w + (\sin b \cos a)\cos w + \cos b \cos f \sin w\Big\} \cos f_o + \Big\{-(\sin a \sin b)\cos f + \cos b \sin f\Big\} \sin f_o \tag{2}$$

where f_o is the declination of the sun,

f is the latitude of the site,

w is the hour angle measured in solar time from 6 o'clock,

a is the azimuth of the slope measured from east or west, negatively to north and positively to south,

b is the gradient of the slope measured in relation to the horizontal.

If I_d is the daily total direct insolation, then

$$I_d = \int_{w_1}^{w_2} I_s \, dw \tag{3}$$

where w_1 and w_2 are the times of sunrise and sunset respectively.

Although the mathematical integration of the right hand side of this equation is not possible, the total of the instantaneous values will give the same result as the integrated values if a sufficiently short time period is chosen. Thus,

$$I_d = \sum_{w=w_1}^{w_2} I_s \Delta w \tag{4}$$

where Δw is a sufficiently short time period to obtain the daily total.

3. The Computer Programming

For practical purposes when computing the value for a certain time period such as a day, it is essential to know what is the maximum interval which will give the same value correct to the first decimal as is obtained when using a time interval of one minute. The desired time interval was found

TABLE ONE

Table of Direct Insolation for Slopes of Different Angle and Azimuth in Latitude 45°N under Selected Atmospheric Transmissivities

TRANSMISSIVITY= 0.60 SUMMER SOLSTICE

ANGLE OF SLOPE	AZIMUTH OF SLOPE -90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
0.0	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8	496.8
10.0	469.5	469.8	470.7	472.2	474.1	476.6	479.4	482.5	485.8	489.3	492.7	496.0	499.1	502.0	504.4	506.3	507.8	508.7	509.0
20.0	428.0	428.6	430.3	433.2	437.1	441.9	447.5	453.9	460.9	468.0	474.9	481.5	487.6	492.9	497.4	501.0	503.6	505.2	505.7
30.0	373.4	374.3	376.9	381.1	386.7	394.2	403.7	414.5	425.8	436.8	447.2	456.6	464.8	471.7	477.4	481.8	484.9	486.7	487.4
40.0	307.6	308.7	312.0	317.3	325.1	337.8	353.2	369.4	385.1	399.6	412.6	423.6	433.0	440.3	445.8	449.9	452.6	454.1	454.6
50.0	232.3	233.7	237.6	244.0	259.2	280.2	301.9	322.8	341.8	358.6	372.8	384.4	393.4	399.9	404.4	407.1	408.4	408.6	408.8
60.0	150.0	151.5	156.0	173.3	200.8	227.9	253.6	277.1	297.7	315.2	329.2	340.1	347.7	352.3	354.4	354.5	353.5	352.0	351.4
70.0	66.7	73.2	94.2	124.1	154.2	183.1	209.6	233.3	253.8	270.4	283.2	292.2	297.3	299.0	297.8	294.6	290.2	286.3	284.7
80.0	35.1	42.6	63.1	90.1	117.9	144.8	169.9	192.0	210.7	225.3	236.0	242.3	244.3	242.5	237.3	230.0	221.3	214.0	211.3
90.0	21.1	27.2	43.5	65.5	89.0	112.3	134.1	153.3	169.2	181.1	189.0	192.2	190.9	185.3	176.0	163.9	150.2	139.1	134.7

TRANSMISSIVITY= 0.80 WINTER SOLSTICE

ANGLE OF SLOPE	AZIMUTH OF SLOPE -90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
0.0	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4	109.4
10.0	52.6	53.5	56.1	60.3	65.9	72.8	80.6	89.3	98.4	107.9	117.4	126.7	135.4	143.3	150.1	155.6	159.7	162.2	163.0
20.0	3.1	4.7	9.8	18.2	28.8	41.2	55.3	70.8	87.5	105.0	122.8	140.5	157.4	172.8	186.3	197.2	205.2	210.1	211.8
30.0	0.0	0.0	0.0	0.0	7.8	21.1	37.7	57.1	78.6	101.9	126.3	150.9	174.8	197.2	216.8	232.7	244.5	251.6	254.1
40.0	0.0	0.0	0.0	0.0	1.5	11.1	26.9	47.3	71.4	98.4	127.4	157.4	187.2	215.6	240.7	261.2	276.3	285.5	288.6
50.0	0.0	0.0	0.0	0.0	0.3	6.5	20.2	40.0	65.0	94.1	126.1	159.9	194.4	227.5	257.3	281.7	299.7	310.7	314.5
60.0	0.0	0.0	0.0	0.0	0.1	4.3	15.8	34.4	59.0	88.6	122.2	158.3	195.7	232.5	266.1	293.7	314.0	326.5	330.7
70.0	0.0	0.0	0.0	0.0	0.1	3.0	12.5	29.4	52.8	81.9	115.6	152.6	191.6	230.7	266.8	296.8	318.8	332.3	336.9
80.0	0.0	0.0	0.0	0.0	0.0	2.1	10.0	24.9	46.4	73.9	106.4	142.9	181.9	221.8	259.4	290.8	313.9	328.1	332.9
90.0	0.0	0.0	0.0	0.0	0.0	1.5	7.9	20.6	39.6	64.7	95.0	129.5	167.3	206.4	244.2	276.0	299.5	313.9	318.7

TRANSMISSIVITY= 0.75 EQUINOXES

ANGLE OF SLOPE	AZIMUTH OF SLOPE -90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
0.0	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6	369.6
10.0	299.8	300.7	303.6	308.4	314.8	322.8	332.1	342.3	353.1	364.2	375.4	386.1	396.2	405.3	413.2	419.6	424.3	427.2	428.2
20.0	220.8	222.8	228.7	238.6	252.3	269.0	287.9	308.3	329.6	351.2	372.4	393.0	412.1	429.5	444.5	457.0	466.2	471.9	473.8
30.0	135.2	138.3	149.1	166.9	189.7	215.7	244.0	273.7	304.0	334.0	363.6	391.8	418.2	442.1	463.2	480.7	493.9	502.2	505.0
40.0	45.4	54.4	77.1	105.1	136.3	170.0	205.2	241.5	277.9	314.0	349.3	383.0	414.6	443.4	468.8	490.3	506.8	517.3	520.8
50.0	0.0	9.3	33.6	63.8	97.5	134.0	172.4	212.0	251.9	291.4	330.0	366.9	401.5	433.2	461.4	485.5	504.3	516.6	520.9
60.0	0.0	2.4	16.4	40.7	71.6	106.8	145.1	184.8	225.6	266.2	305.7	343.5	379.2	412.0	441.2	466.5	486.8	500.2	505.1
70.0	0.0	1.0	9.3	27.6	53.7	85.5	121.4	159.5	198.9	238.2	276.8	313.8	348.2	380.4	409.1	434.0	454.5	468.7	473.9
80.0	0.0	0.5	6.0	19.5	40.9	68.4	100.2	135.3	171.3	208.1	243.9	278.2	310.2	339.7	366.2	389.4	409.0	423.0	428.4
90.0	0.0	0.3	3.9	13.9	30.8	53.8	81.4	111.7	144.0	176.1	208.2	238.2	266.3	291.5	314.1	334.2	351.4	364.5	369.8

Note: The azimuth of the slope is measured from east, negative to north and positive to south.

to be twenty minutes. Using this interval, tables of the daily total direct insolation at latitude 45°N for the equinoxes and solstices were prepared in steps of ten degrees for all slopes of all aspects and gradients, with the values for the transmissivity of the atmosphere ranging from 0.50 to 0.85 in steps of 0.05 (Table 1). The computation for the transmissivity at a lower value than 0.50 was not made because under such low transmissivities, the contribution of the diffused insolation becomes too large for the estimation of direct solar radiation to be worthwhile.

4. The Application of the Equation

To illustrate the application of the formula maps have been prepared to show how the distribution of direct insolation at Mont St. Hilaire, Quebec, is influenced by topographic irregularities (Figs. 3 - 5). These maps were constructed by using the values from Table 1 to plot radiation totals for each corner of a grid system in which each grid square is equivalent to 150 yards. The topographic map of the area (Fig. 2) was used as a base for the grid from which to obtain the appropriate slope angle and azimuth at each intersection.

5. The Features of the Distribution of the Direct Insolation on Slopes

(i) The map for June 20, 1967, which approximates the summer solstice, shows the most uniform distribution over the rugged ground surface of Mont St. Hilaire. This is because firstly, the orbit of the sun in summer is fairly uniform for south and north slopes, and secondly, the relatively low intensities of a gently tilted north slope are compensated for by a longer

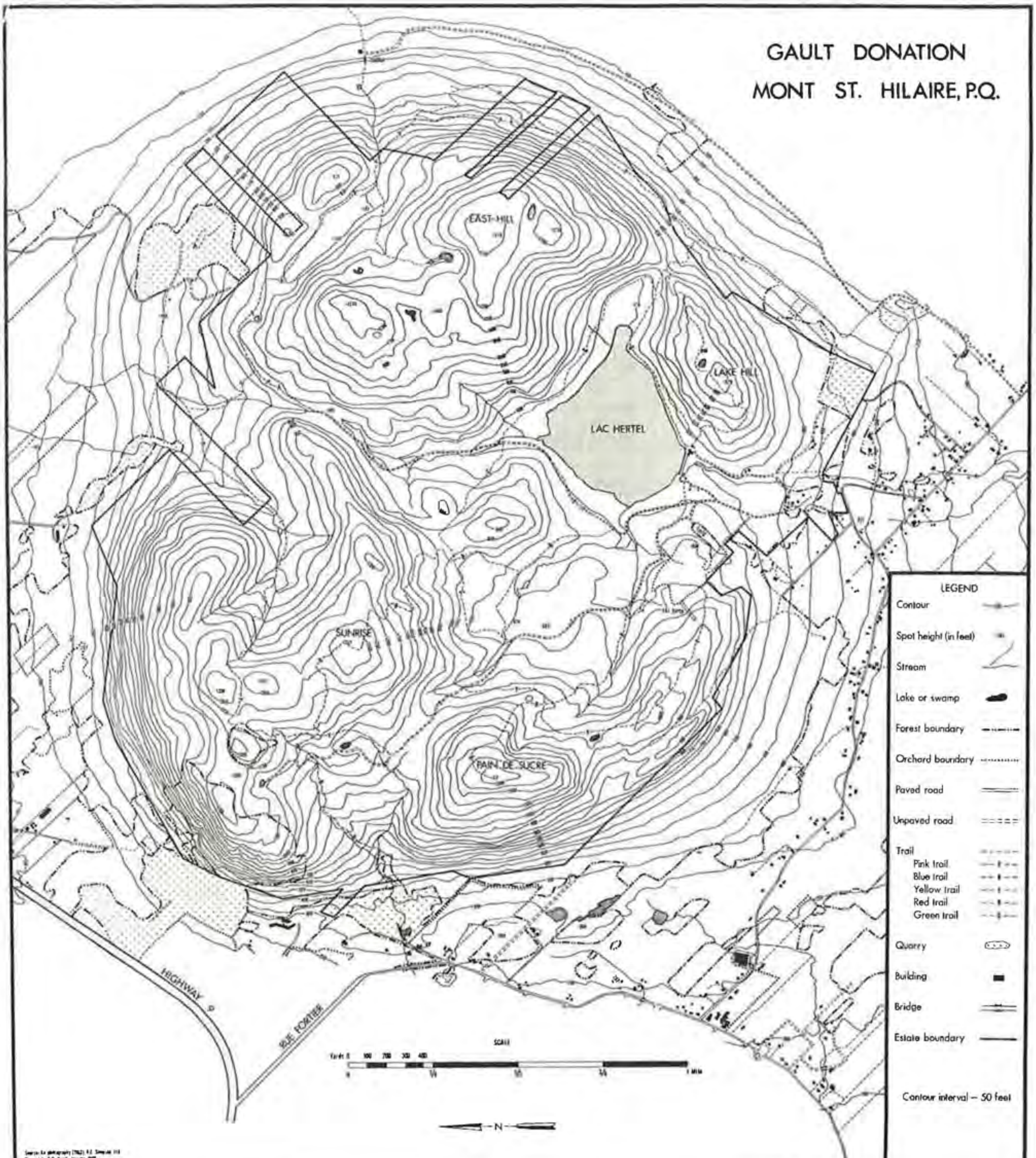

Fig. 2. Contour Map of Mont St. Hilaire, Quebec.

potential sunshine duration than that which exists on a south slope. This fact makes the difference in azimuth less important than the difference caused by gradient, the range of which is relatively narrow in nature.

(ii) The topographic variation is effectively reflected in the map for September 19, 1967, representing the equinoxes. The enormous difference between north and south slopes is explained by the combined effect of longer sunshine duration and consistently larger instantaneous values on the south slope as compared with the north. Maximum values are found on a relatively steep south slope (40^{o} - 50^{o}), while in summer the highest values appeared on a more gentle slope (10^{o} - 15^{o}). For the east and west facing slopes, the azimuth of the slope is more effective than the gradient in causing radiation differences.

(iii) At the winter solstice represented by the map for December 27, 1966, the difference between south and north slopes is as sharp as at the equinoxes if we take the ratio between the slopes, but since the maximum value of insolation is so small, the difference in the absolute values between north and south slopes does not appear as large as that found at the equinoxes. The gradient of the slope loses its significance for the east and west slopes and only the aspect of the slopes determines the major value of the daily total.

6. The Future Project

To evaluate the contribution of insolation to the elements of the heat budget, it is not satisfactory to deal only with direct insolation. Both diffuse radiation and surface albedo need to be considered. To approach this

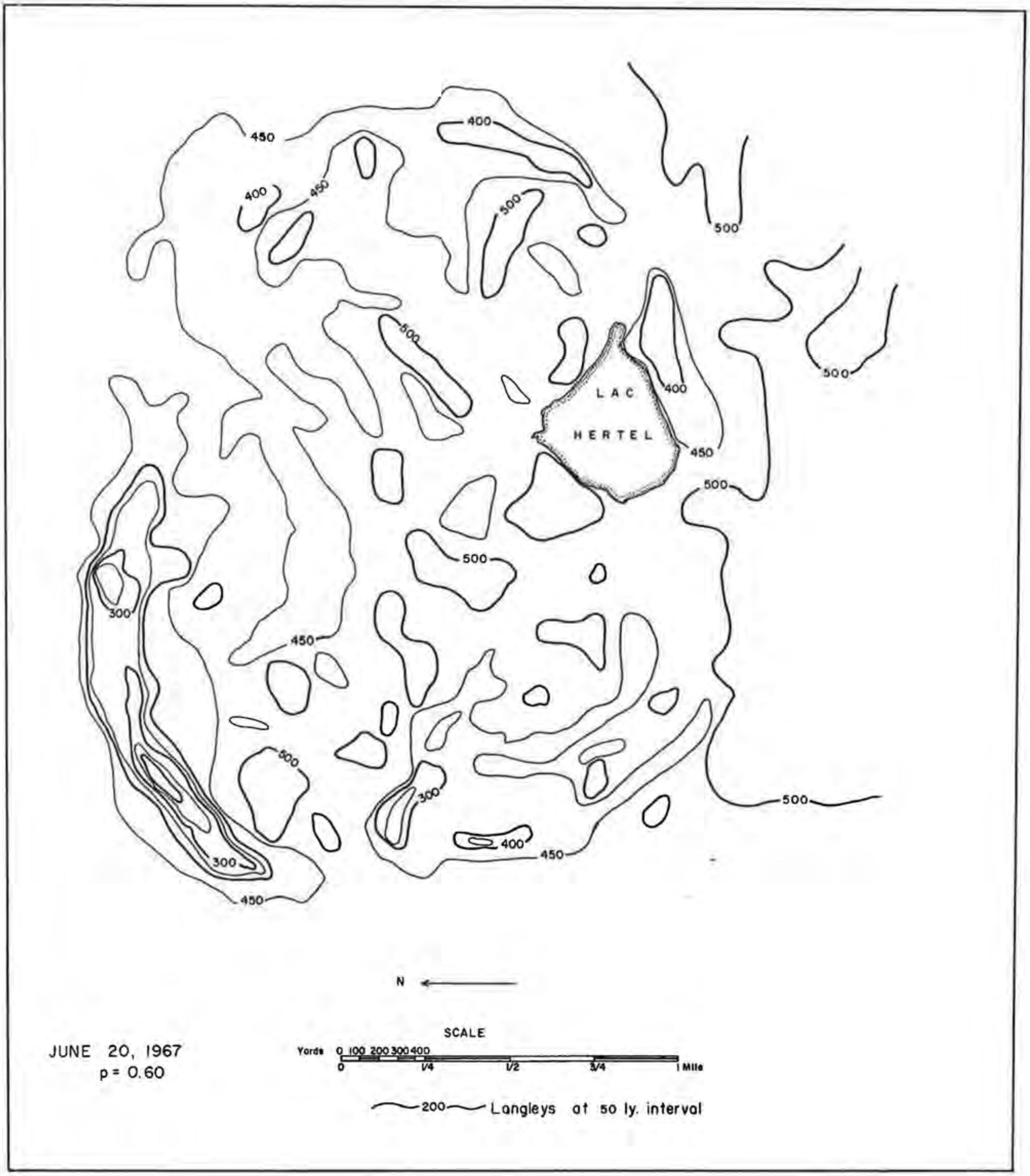

Fig. 3. Distribution of Direct Solar Radiation Totals at Mont St. Hilaire, June 20, 1967.

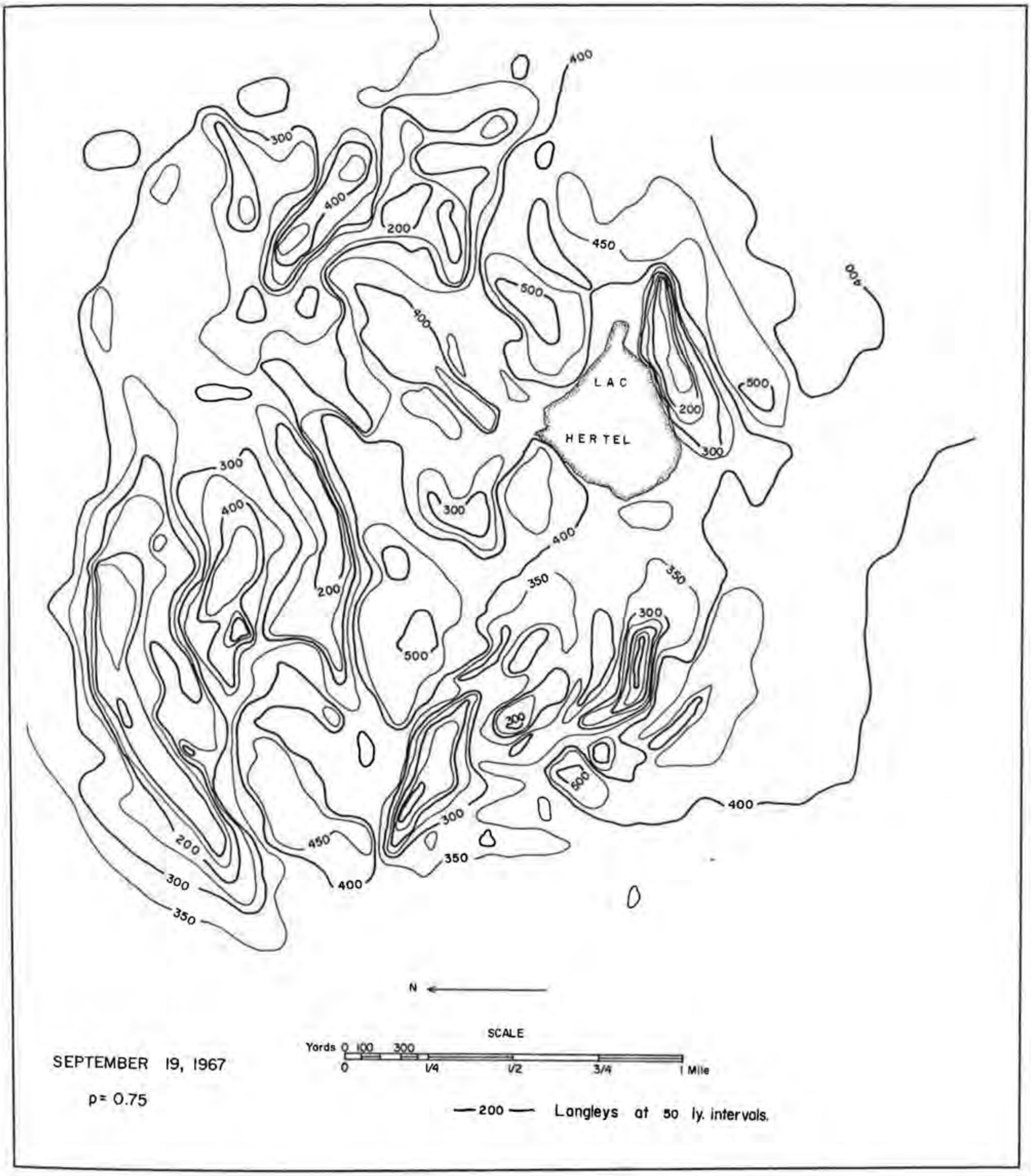

Fig. 4. Distribution of Direct Solar Radiation Totals at Mont St. Hilaire, September 19, 1967.

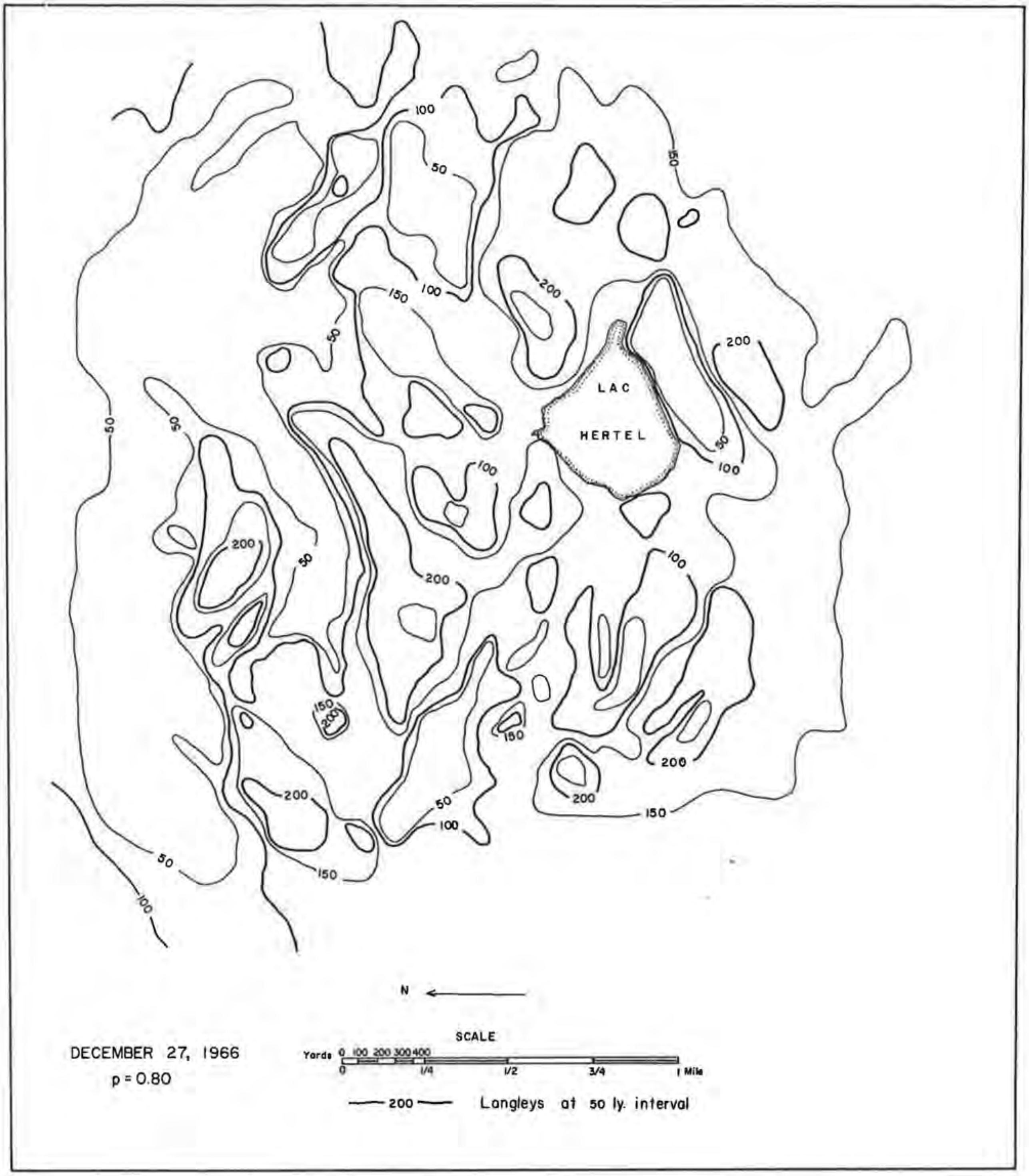

Fig. 5. Distribution of Direct Solar Radiation Totals at Mont St. Hilaire. December 27, 1966.

aim, a larger programme is now being prepared in which Kondrat'yev's equation for sky-diffuse radiation will be adopted to compute the contribution from direct and diffuse radiation separately, so that mapping for overcast conditions is possible. In addition, the albedo for each point on the map will be put in to subtract the reflected part. Since the distribution of long-wave radiation can be expected to be fairly homogeneous, a net short-wave radiation map of this type will help to estimate both the evaporation and the sensible heat flux at the surface of the ground.

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RESEARCH REPORT

The first number of CLIMATOLOGICAL BULLETIN contained an article outlining the development and current plans for the climatological programme at McGill University (Garnier, 1967). It was there stated that ".... the existence of a separate Department of Meteorology [since 1959-60] .... enables the Department of Geography to concentrate more completely on microclimatological studies, both pure and applied, with emphasis upon their comparative [geographical] aspects and their relationship to prevailing weather characteristics. This is the direction which the climatological programme [in geography] is now taking".

During the twelve months which have elapsed since that statement was written, the lines of development have become more precise. The fundamental philosophy underlying the programme is that microclimatological characteristics within any territory represent the response of local surfaces to the prevailing atmospheric conditions and energy inputs. The result is often a complex pattern, the nature of which is difficult to monitor if studies are concentrated solely or mainly on measuring detailed effects. A more meaningful approach is to recognise these effects as responses to the inter-connections between physical parameters like slope, aspect, soil properties and vegetation characteristics on the one hand, and energy fluxes and prevailing atmospheric circumstances, such as cloud, wind, and humidity on the other. By measuring these fundamental conditions and carefully sampling the consequences of their inter-connections in selected localities and under different synoptic situations, it is possible to achieve not only an understanding of the pattern of microclimatological conditions themselves, but also an appreciation of the role of the surface in the total energy and moisture balances under different atmospheric states. Moreover, such an approach to microclimatological investigations suggests a way whereby much of the detailed and highly varied microclimatic pattern can be estimated from terrain and weather chart analysis without the need for a dense network of observing points.

Among the factors involved in such a study, the topographic variation of solar radiation is fundamentally important. Accordingly a major effort towards evaluating this is being made. The article by Atsumu Ohmura elsewhere in this BULLETIN (see pp. 42-53) briefly describes a formula he has developed for this purpose and programmed for use with an IBM 360 computer. The article also illustrates how the formula has been used to map direct short-wave radiation for three specific days at Mont St. Hilare. A more substantive paper describing the formula has been prepared by Ohmura and B. J. Garnier for publication elsewhere.

Immediate developments in relation to this formula and its use consist in making a programme for the computer mapping of direct short-wave radiation, preparing tables for use at different times of year, and investigating the importance and methods to be used for sky-line correction when mapping the radiation distribution. This work is being undertaken at the moment in respect of latitude 45°N and latitude 13°N. The former latitude is that of Mont St. Hilaire and the latter that of Barbados. Thus, the pilot studies based on the former research base are being extended to a tropical location for comparative purposes. In the latter area, a special study into the radiation intensities during the early hours of the day and their importance for the subsequent development of convection is being planned as a doctoral research project by B. K. Basanayake, who will also assist B. J. Garnier in the more general radiation studies of the island.

Since the radiation work outlined above is an essential background to the whole surface energy budget and its estimation, energy budget investigations at both Mont St. Hilaire and Barbados are being planned. Some discussion of the recent developments in the latter area will be found on pp. 18 - 22 of this BULLETIN. A similar energy budget investigation at Mont St. Hilaire is to be undertaken by Atsumu Ohmura during the coming summer. In this work he will have the benefit of being able to draw on Richard G. Wilson's detailed study of the microclimate of part of the forest at Mont St. Hilaire, now being written-up as an M.Sc. Thesis, and Wayne Rouse's earlier work (Rouse, 1965, 1967).

Although the radiation and energy budget studies at Mont St. Hilaire and in Barbados account for a substantial part of the research activity within the climatological programme at present, further dimensions are being added by Tim R. Oke who is developing work in urban climatology and in the aerodynamic approach to energy budget investigations.

These studies in urban climatology are expected to take about five years to complete. Initial studies are investigating the structure of the "heat island" associated with a large metropolitan area, such as Montreal. A brief look at a pilot investigation in this field is given in the article on pp. 36 - 41 of this BULLETIN. The primary aim of this work is an understanding of the three-dimensional structure of the heat island.

The major emphasis in the programme as a whole, however, lies in a study of the component fluxes in the energy balance of a city. This summer a start will be made in measuring the radiation balance fluxes by replicating the Mont St. Hilaire equipment at a city location. This study will be concerned with both the spatial and temporal variations of solar and infra-red radiation with special reference to the effects of pollution. Later studies will attempt an estimation of the contributions to the energy balance of city surfaces that are made by other factors. These components include the heat stored in building materials and produced by combustion processes, and the very important partition of energy between the sensible and latent heat fluxes.

During the coming summer, T. R. Oke and a graduate student will be involved in a co-operative micro-climatic project at Simcoe, Ontario, in conjunction with Drs. Davies and Rouse of McMaster University. By joining together at a single research site in this way, it is possible to gather enough instrumentation to attack problems that a single institution could not encompass. Such a problem is that of advection of air from one surface to another, and the resulting progressive changes in the microclimatic properties of the air. An understanding of advective effects is a necessary prerequisite if geographers are to progress from point studies towards the spatial variation of microclimates. In the work at Simcoe, an attempt will be made to formulate a universal relationship for the growth of the internal boundary layer following a change in surface characteristics.

The research described above constitutes the chief research activity currently under way within the programme of comparative microclimatology in the Department of Geography at McGill University. It is hoped, as soon as possible, to add to it a systematic study of the radiation and energy balances of lake surfaces beginning with a pilot study of Lac Hertel, Mont St. Hilaire, and possibly other water surfaces nearby, and extending it to the lakes in the vicinity of the McGill University Sub-Arctic Laboratory at Schefferville. This extension of work is necessary for two main reasons: to include inland water surfaces and their responses as an integral part of the fundamental investigations described at the start of this report as basic to the research programme's outlook; and to extend the comparative aspects of the programme to include the Sub-Arctic, and ultimately the Arctic, as well as the tropics.

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McGill University.

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NEWS AND COMMENTS

Tim R. Oke joined the staff of the Department of Geography in September, 1967, as Assistant Professor of Climatology. Professor Oke graduated in geography at Bristol University, England, before coming to Canada to study at McMaster University. He completed his M.A. at McMaster in 1964 and obtained a Ph.D. from the same University in November, 1967. His dissertation was entitled "Super Surface Minimum Temperatures at Night" and represented a development on his work for his Master's thesis in "Temperature Variations in a Fine Sandy Loam. Professor Oke's present research is concerned particularly with Urban Climatology and the aerodynamic aspects of energy budget measurements (see pp. 36-41 and 54-56 of this Bulletin).

Since the beginning of September, 1967, J. Noël Pelletier has been the Chief Observer at the Mont St. Hilaire observation site. Mr. Pelletier joins the staff of the McGill Climate Programme after three years' experience as an observer, first with ARDA during 1965 where he was Assistant Meteorologist in the Bureau d'Aménagement de l'Est Québec at Mont Jolie, and then, from December 1965 to August 1967, at the McGill University Sub-Arctic Laboratory at Schefferville.

At the end of October, 1967, Dr. W. C. Swinbank of the Meteorological Physics Division of CSIRO, Australia, gave a seminar on his recent work in the aerodynamic approach to energy budget measurements. Dr. Swinbank also discussed his work informally with graduate students and advised on the research programme, particularly in respect of work in progress at Mont St. Hilaire.

Another recent visitor was Professor Melvin E. Marcus of the University of Michigan, Ann Arbor. Professor Marcus gave a seminar on the interdisciplinary approach in research work based on his experience in glacier investigations in Alaska.

Two University Lecturers from overseas universities are currently studying in the doctoral programme in climatology at McGill. They are B. K. Basanayake, Lecturer in the University of Ceylon, and Richard F. Fuggle, Lecturer in the University of South Africa, Pretoria, from 1966 to 1967. Mr. Basanayake's field of interest lies in radiation studies in the tropics and he plans to research in Barbados on the contribution of solar radiation during the morning to the development of convection through the day. Mr. Fuggle will be working in the field of urban climatology.

Topics under investigation by candidates for the Master's degree include: (a) Topographic Influences on a Forest Microclimate (R. G. Wilson); (b) Precipitation Characteristics in Central Labrador (P. R. Grevatt); (c) An Analysis of Weather Conditions in the Rupununi District of Guyana (C. Kagenda-Atwoki); (d) Methods of Calculating and Mapping the Insolation on a Slope (A. Ohmura); (e) Temperature Variations in Relation to Typical Weather Situations in Central Labrador (D. Leung); (f) Moisture Conditions in the Savanna Region of West Africa (K. Swami).

McGill University has for long carried an international reputation for studies in many fields. The University's international flavour is well-represented in climatology. The nationalities of the eight people working for doctoral or master's degrees in climatological subjects are distributed as follows: Canadian (1), American (1), Japanese (1), Chinese (1), South African (1), Ugandan (1), Indian (1), Singhalese (1).

McGill University
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C L I M A T O L O G I C A L R E S E A R C H S E R I E S

No. 1. Two Studies in Barbadian Climatology
by Wayne R. Rouse and David Watts.
65 pp., July 1966, price: $6.00.

No. 2. Weather Conditions in Nigeria
by B. J. Garnier.
163 pp., March 1967, price: $7.50.

No. 3. The Climate of the Rupununi Savannas - A Study in Ecological Climatology
by David B. Frost.
92 pp., December 1967, price: $6.50.

No. 4. Temperature Variability and Synoptic Cold Fronts in the Winter Climate of Mexico
by John B. Hill.
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