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THE ORIGINS AND PURPOSE OF THE McGILL SUB-ARCTIC RESEARCH LABORATORY

by

R. Norman Drummond*

The first major study by a McGill geographer in the Canadian Sub-Arctic was entitled "The Climate of the Eastern Canadian Arctic and Sub-Arctic, and its Influence on Accessibility". The interests of its author, F. Kenneth Hare, in climate and vegetation and his influence on a decade of graduate students led to many pioneering studies in the physical geography of north-eastern Canada (Blake, 1953; Burbidge, 1950; Drummond, 1950; Hare, 1950; Montgomery, 1950; Orvig, 1952).

Portions of these studies were office-based, but their major contributions came from the results of field investigations. The field parties were mounted from Montreal or Goose Bay, necessitating long lines of communication and supply, and were confined to the summer season. Why not have a base - a permanent, year-round station - in the main area of interest? From such a centre parties could more easily move to their field research areas and at such a station work on year-round and long-term projects could be undertaken. Here too, staff and students from many disciplines could share in the modification and development of research techniques applicable to the still "unknown" region. Where previously broad scale, reconnaissance methods had been used, more detailed and instrumented techniques could now be employed. New problems could be identified, and, it was hoped, successfully analysed and solved.

The region of prime interest was the 500,000 square mile peninsula of

* R. Norman Drummond is Associate Professor of Geography at McGill University and was the first Field Director of the McGill Sub-Arctic Laboratory from 1954-57.

Labrador-Ungava, but its "climate and accessibility" raised obstacles of cost and logistical support to the establishment of a field laboratory. Opportunities to overcome these arose with the development of the deposits of iron ore in the vicinity of Knob Lake, the construction of the town of Schefferville and the railway link to Sept Iles. The close co-operation of the Iron Ore Company of Canada, the Tower Construction Company and the financial assistance of Mr. J. W. McConnell of the McGill Board of Governors, culminated in August, 1954 in the construction of the first building of the McGill Sub-Arctic Research Laboratory at Schefferville, Quebec (Fig. 1).

Two factors, one logistical, the other functional, determined the exact site of the laboratory building near the town's airstrip. Water supply was the logistical factor, and since the town water was then a mile and a half away, a well was successfully drilled where the functional factor could be carried out. This function was the operation of a first order weather reporting service for the Department of Transport (Meteorological Branch). This required that weather observations representative of conditions at the air-strip be taken twenty-four hours a day and that an office be accessible to aircrew for information services. It was this contract with the Department of Transport that provided the continuing financial support to begin and maintain the operation of the laboratory and its academic and research programmes.

Thus, on October 1, 1954, McGill officially took over the duties of the Knob Lake weather station from the Hollinger Ungava Transport Company, a subsidiary of the Iron Ore Company, which had been operating a station since 1948. Their early records are incomplete and until summer 1954 the station had been located at the old airstrip some five miles east of the present site.

It is not illogical that the meteorological observing programme should be the main financial support of the laboratory, for weather and climate,

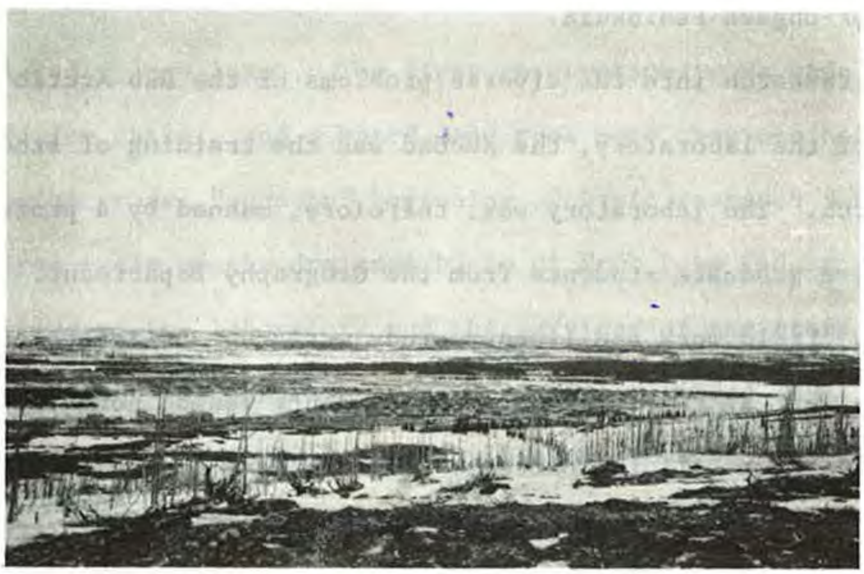

Fig. 1. Upper photo: The McGill Sub-Arctic Laboratory.
Lower photo: A general view looking west over Schefferville. The McGill Laboratory is in the group of buildings in the middle left of the photograph.

both past and present, play a vital role in the many facets of both the physical and human geography of the region. Hence, climatology has always been one of the main fields of investigation, both in itself and in its relationship to other subjects.

The specific nature of the research undertaken can best be seen from the bibliography of publications of the McGill Sub-Arctic Research Laboratory and described in the Tenth Anniversary Volume (Adams, 1967). Within the unifying theme of the Sub-Arctic, diverse subjects - from the growth rate of spruce trees to the rate of coastal uplift, from the history of exploration to the turnover of labour force in mining towns - met the attention of McGill staff and students and visiting researchers from other institutions. Studies in physical geography dominated, and, particularly under the guidance of Dr. J. D. Ives, concentrated on problems related to the glaciation and deglaciation of the Labrador-Ungava Peninsula.

While research into the diverse problems of the Sub-Arctic was the prime objective of the laboratory, the second was the training of students to do this research. The laboratory was, therefore, manned by a professor and from three to five graduate students from the Geography Department. Seminars, discussions, field work and library study were the media for learning. Following a year at the laboratory the students would, normally, complete their studies at McGill in Montreal. Summers gave undergraduate students opportunity to be field assistants to the staff and graduate students or to work on the observing programmes at the station.

A third objective of the laboratory was to provide facilities for students and staff from other departments and institutions. The majority of these also came during the summers and were primarily botanists, zoologists and geographers.

The weather observing programme was soon expanded, and many additional meteorological parameters, with appropriate instrumentation, were added. Some rivaled the Toronto headquarters of the Department of Transport for complexity. With the growing number of "routine" observations, one of the staff positions was filled by a full-time "chief observer", who was not a graduate student. He assumed major responsibility for the weather and, later, seismic, observations and thus released the field director and students for other scientific duties. These additional "jobs" which at first irked the "overworked" staff in the early years, became routine to subsequent "Knob Lakers" and provided material for research and thesis topics. One such extra job was the measurement of the thickness of lake ice. This was "imposed" by a terse teletype message which arrived on a bitter stormy day in early Winter of 1954-55. The construction of the mid-Canada defense line was about to begin and knowledge of lake ice thickness was need for the supply planes which were to land on isolated frozen lakes. The first observations were made with an axe, a home-made ice chisel, and a board, and took more than one hour per hole. This was the crude, "unhappy" beginning of basic research into the total hydrological cycle of the drainage basin of Knob Lake (Adams, 1967).

The facilities of the laboratory and the services of the staff were utilized in other observing programmes which in turn provided funds and/or research topics. From 1954 to 1960 the McGill staff took recordings for the Dartmouth College Ionosphere Research Program in radio-wave propogation using equipment installed and maintained by Dartmouth and Stanford University. Seismic activity was recorded for the Dominion Observatory on portable equipment in 1956-57. This led to the installation of a major seismic vault in 1962 and a continuing programme. The most profitable, from the geomorphologist's view, was the series of recording stations set up in the town and in the iron ore mines to measure permafrost. This was undertaken in conjunction with the National Research Council and the Iron Ore Company of Canada and continued until most of the sites were destroyed in the course of mining operations.

This direct involvement and application of research led to a regular financial grant from the Iron Ore Company and marked the beginning of outside support for the work of the laboratory. The laboratory was always an integral part of the Geography Department and hence funds for both general and specific research came from agencies which usually support university research. These included the Arctic Institute of North America, the Centre d'Etudes Nordiques at Laval, the Defense Research Board and the Department of Mines and Transport (Geographical Branch). Dr. S. Orvig and other memebers of the Arctic Meteorology group at McGill, with support from the U.S. Airforce, Cambridge, Massachusetts, have been active participants in the climatological work since 1954. The laboratory participated in the aurora borealis programme of the International Geophysical Year and is now actively involved in the International Hydrologic Decade.

The service function of the laboratory included providing weather information to the local mine operations, townspeoplé, and outlying prospectors and construction crews. But weather data for aircraft was the most important. During construction of the mid-Canada line - 1955-57 - a Department of Transport aviation forecaster was assigned to the station to brief aircrews. With the establishment of the R.C.A.F. station in 1955, a close link developed between the laboratory and the personnel of the airbase and the operating company, The Canadian Marconi Company. This included the provision of messing facilities to the McGill students (who had previously done all their own cooking) and maintenance of laboratory vehicles. With modifications, these arrangements continued until the defense line was closed in 1965.

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CLIMATOLOGICAL RECORDS OF THE McGILL SUB-ARCTIC RESEARCH LABORATORY

by

Bruce Findlay*

The McGill Sub-Arctic Research Laboratory located at Schefferville, Labrador-Ungava (fig. 1), was established in September 1954. Most of the financial support for the station comes from a contract with the Meteorological Branch, Canada Department of Transport, whereby the University operates a Class A surface weather station on a continuous basis. The Laboratory staff have been, in the main, graduate students, and it is not surprising that the student weather observers have profited from their routine observational duties by producing considerable material and theses on climatological and related themes. The greater part of this material has been published in the McGill Sub-Arctic Research Papers and a list of climatic studies printed in these Papers has been included at the end of this article.

General Observations

Within a year of the establishment of the Laboratory the basic complement of regularly-used instruments was almost the same as the present day. Therefore, continuous records are available for the following meteorological parameters, the observations being taken in the meteorological enclosure attached to the Laboratory (fig. 2). A selection of mean data compiled from the results of these observations is given in Table 1.

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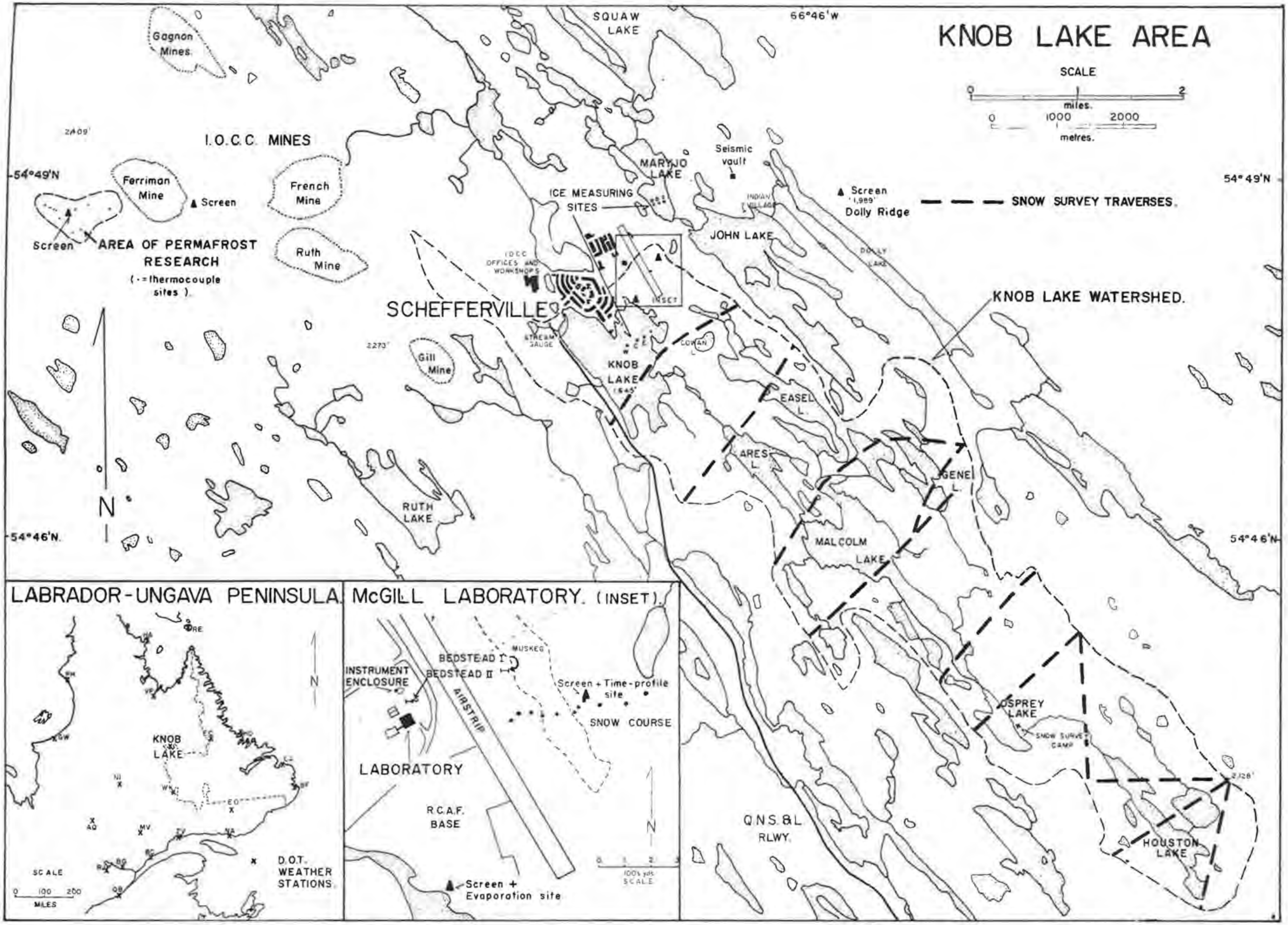

Fig. 1. Location Map of Schefferville and District.

TABLE 1

Climatic Data for Knob Lake, Schefferville.

Means for period 1954-66

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature ^{o}F	-6.9	-5.5	5.4	19.9	33.1	46.8	54.2	51.2	41.6	29.9	16.5	-1.5	23.7
Total Precipitation Ins.	1.88	1.22	1.24	1.31	2.10	3.50	3.56	4.24	3.41	2.52	2.51	1.66	29.15
Days with Measurable Precipitation	16	13	13	11	15	16	17	20	19	18	19	16	193
Snowfall - Inches Depth	17.5	12.0	11.7	11.7	11.0	2.5	TR	0.9	9.0	13.0	21.9	16.0	127.2
Rainfall - Inches	0.13	0.02	0.07	0.13	1.00	3.25	3.56	4.15	2.50	1.22	0.33	0.07	16.43
Sunshine hours	76.3	116.8	157.2	176.9	161.1	189.6	176.2	144.6	94.3	62.7	42.9	62.1	1467.0
Wind speed - m.p.h.	10.7	10.3	10.7	10.3	10.8	10.5	10.2	10.4	12.1	11.8	11.2	10.9	10.8 (avg.)

Parameter	Instruments	Schedule for Measurement
air temperature measured in a standard shelter at 1.5 metres above the ground surface	standard sheathed thermometers	hourly; max. & min.
	thermograph	every 6 hours and continuous
humidity	motorized psychrometer, hygrograph	hourly, continuous " "
pressure	mercury barometer, barograph	hourly, continuous " "
wind at 10 metres	U2A and type 45 cup anemometers	hourly, continuous
upper wind	pilot balloon	every 6 hours
rainfall	standard 3" gauge, heated tipping bucket gauge	every 6 hours and continuous
snowfall	standard 5" gauge with Nipher shield	every 6 hours
sky cover, cloud or obscuration type	observer	hourly or more frequently
horizontal visibility	observer	hourly or more frequently
sunshine	Campbell-Stokes recorder	continuous

Other phenomena have been measured from time to time but the records are not continuous. A surface weather map for 0900Z is drawn daily and filed at the laboratory.

Solar Radiation

Incoming solar radiation was measured from 1957 to 1961 with an M.S.C. "G" type bi-metallic actinograph, although there were a few breaks in the record. In 1962 this instrument was replaced by two 180^{o} Epply pyrheliometers, thus giving the total radiation flux, but in 1965 these instruments were removed

Fig. 2. Two views of the Meteorological Enclosure at the McGill Sub-Arctic Laboratory.

Fig. 3. Floating Class 'A' pan in Knob Lake. Schefferville in the background.

for technical reasons. At present two Suomi and Kuhn economical radiometers are the only instruments measuring radiation at Knob Lake, although it is hoped to install a "G" type actinograph again shortly. The records for solar radiation are available from various Department of Transport publications and are not kept at the station.

Evaporation

From 1956 to 1959 summer evaporation was measured by two black Bellani atmometers and two fuel drum evapotranspirometers of the Thornthwaite-Garnier design. A break in the records occurred during 1960 and 1961, but from 1962 to the present a Class 'A' pan has been used each summer (fig. 3).

The atmometer measurements have also been resumed, with the Bellani instruments replaced by a black porous disc atmometer which is less subject to frost damage. The summer evaporation season normally lasts from the first of June to the middle of September. During the winters of 1964-65 and 1966-67 snow evaporation was also calculated and measured.

Soil Temperatures

From the summer of 1964 to the present, earth temperatures have been measured at 1, 10, 20, 50, 100 and 150 cm at the Laboratory site with M.S.C. remote reading thermistors. These observations have been made four times daily.

Run-off

In August 1964 a stream gauge was installed at the principal outlet of Knob Lake. The recorder keeps a constant account of the run-off from a 13.5 square mile watershed. The watershed research programme is part of the Canadian scheme for participation in the International Hydrologic Decade. Some trouble has been encountered with the recorder but the records do not have great lapses.

Snow Survey

Beginning in the International Geophysical Year, the Laboratory has records of snow conditions continuing to the present. The programme has gradually improved in quality with the introduction of such instruments as the Canadian Snow Kit (N.R.C.) in 1958 and the Mount Rose Snow Sampler in 1964. A regular 10 station snow course was established in 1961, and each year a daily depth figure is obtained at each station and a weekly water equivalent. Each month it has been the practice to sink a pit in the forest snow and describe the profile with respect to layer determination, desnity, hardness and temperature. Since 1964 detailed snow surveying has been done at several other sites within the general Schefferville region.

Fig. 4. The thermometer screen at Dolly Ridge (see fig. 1 for location) with Schefferville in the background.

Ice Survey

Ice thickness measurements have been made on Knob Lake and other water bodies weekly since the inception of the Laboratory. From 1959 onward thicknesses have been measured weekly on two lakes at six sites, and an account has been kept of the role of snow-ice or "white ice" as well as the regular "black ice". Observations of the winter water and ice temperatures by means of thermocouples have been conducted from the beginning of the winter of 1962-63 to the end of the winter of 1965-66. Instrument damage has prevented the continuation of the programme.

Regional Air Temperature Programme.

Standard Stevenson screens with maximum and minimum thermometers have been located at varying sites for different occasions. Accounts of these stations can be found in the following McGill Sub-Arctic Research Papers reports listed in the bibliography following this article: Davies (1962), McCloughan (1962), Westlake (1964), Findlay (1966), Dyke (1967). Fig. 1 shows the location of the stations and fig. 4 a photo of the installation at Dolly Ridge.

Station	Elev.	Site	Data Collected	Original Purpose	Date Est.
Ferriman Ridge	2500	tundra	temp., wind	permafrost investigation	1959
Ferriman Mine Dry	2100	tundra	temp.	permafrost investigation	1959 closed 1965
Dolly Ridge	2000	tundra	temp., wind	wind chill	1961
Woods	1670	spruce forest	temp., wind 1965-67	snow survey	1961
Lake	1648	beach	temp., evaporation	lake ice	1962

Permafrost Research

In co-operation with the Iron Ore Company of Canada and the National Research Council, the Laboratory staff have measured the ground temperatures at various sites in the mining area to depths of hundreds of feet on a regular basis. These records are continuous since the summer of 1959.

Special Studies and Instruments

Several special instruments owned or on loan to the Laboratory have given support to specific climatological problems.

In the fall of 1966 the Laboratory received a Fischer-Porter totalizing precipitation gauge with an electric (battery) punch tape readout as a loan from the Meteorological Branch for testing purposes (fig. 5). At the same time McGill University Physics Department made available a 12' diameter pneumatic bag known as a "snow pillow" which when filled with antifreeze will weigh the amount of snow on the surface by measuring the pressure with a certain known amount of snow water on the surface. In early 1967, the Meteorological Branch delivered a special tipping bucket rain gauge equipped with heating elements and an Alter shield. The purpose is to run tests with freezing precipitation at various temperatures and wind conditions.

Fig. 5. The Fischer-Porter totalizing precipitation gauge installed near the McGill Laboratory.

The totalizing precipitation gauge is equipped with a special alkaline battery which has three times the life of its regular counterpart and withstands extreme cold snaps quite well. Turbulent flow near the gauge orifice (8" diameter) is arrested by an Alter shield, and the solid precipitation falls directly into a constantly weighed receptacle which is charged with antifreeze and an oil slik (to prevent evaporation). A binary tape which is punched every five minutes shows the gauge content, thus making fall intensity studies possible.

The snow pillow filling tube was connected to a stilling well and a water level recorder was installed. As the winter passed it was possible to gauge the snow-water increment directly as each storm occurred once the pillow and well were calibrated. Unfortunately a light winter snowfall and recurrent trouble with the level recorder precluded the usefulness of this instrument to a considerable extent.

As expected the heated tipping bucket gauge did not measure very well in mid-winter, for the particles were too light to lodge in the shallow orifice cavity. Wet snow and freezing precipitation were retained quite well. Some of the lighter falls may not have had time to congeal into droplets and enter the bucket prior to a significant evaporative loss.

These instruments constitute a portion of the hydrological programme the Laboratory is carrying out as part of the Canadian participation in the International Hydrologic Decade. Other instruments used in this connection are an Ott water level recorder, an Ott runner-type current meter including a special runner for oblique and turbulent flow, a sodium dichromate injecting apparatus (Neyrpic) for chemical estimates of stream discharge, two fuel drum evapotranspirometers, an extra Class 'A' evaporation pan and several extra standard rain gauges.

Other equipment available at the Laboratory of interest to climatologists include thermographs, a hygrograph, and hygrothermograph, a sling psychrometer, a spring-operated ventilated psychrometer, two Suomi and Kuhn economical radiometers, a Thornthwaite wind profile set (4 sensitive anemometers to 160 cm), a semi-portable totalizing anemometer with a ten-minute wind counter, thermistor and thermocouple strings including the attendant wheatstone bridges and potentiometer. The Laboratory also has a drying oven, balances, drafting equipment and a well-equipped library.

Future Research and Limitations

The environment of central Labrador-Ungava and the character of the Laboratory staff have decidedly shaped at least the rate of research development of the Institution.

For instance, the persistency of long cold periods has made it difficult to use battery operated equipment for much of the time, although the success with the somewhat expensive alkaline battery which is included with the Fischer-Porter gauge suggests that this problem may be soon overcome. Clockwork would seem to be the best drive for most recording instruments in a sub-Arctic setting although this too is not foolproof in very cold weather. Contamination of the mechanism with fine snow particles and dust is a further problem. The high frequency of moderate winds means that a thermocouple-potentiometer installation cannot be used as much as would sometimes be desirable, and consequently, thermistors and wheatstone bridges have been found to be more successful.

At the present time it is hard to maintain complicated mechanisms at the Laboratory. Most of the students understand only the elementary principles of semi-complicated instruments until perhaps toward the end of their tour of duty. Unless the Laboratory engages a competent instrument technician and provides him with an equipped workshop this limitation will continue. Until this defect is rectified the Laboratory would be wise to consider carefully the adoption of future permanent programmes in order to avoid technical over-commitment.

A future profitable line of climatic investigation would seem to be a study of the varying conditions in the forested and open zones of the lichen woodlands in various depressional, level, and ridge sites (fig. 8). Despite some considerable work already completed toward understanding the heat and moisture balance in these environments, much remains to be done. In general, too, the field of hydrology has only been touched.

Synoptic and dynamic climatology were intensively dealt with by Barry (1959, 1960) who hoped to unmask some of the controversy surrounding the formation of an ice sheet on the Quebec-Labrador Plateau. However, even now

Fig. 6. Two views of open woodland in the Knob Lake area.

the regional precipitation distribution is imperfectly understood and much work remains to be done.

This last winter has seen a study emphasizing the snowfall distribution in the local forest. The study has led to the construction of simple gauges in order to assess the effects of turbulence and forest interception, and at present, experiments are being made with a prototype of a simple pluviometer which will tilt into the wind according to the force and will shift according to the direction. It is hoped that instruments such as this will help refine some concepts of this very complicated phenomenon.

These are but a few of the potential developments in sub-Arctic climatological research which might be undertaken using the Laboratory as a base.

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UNE NOTE SUR LES INFORMATIONS METEOROLOGIQUES DISPONIBLES A KNOB LAKE

par

J. N. Pelletier*

Toutes les données qui sont publiées et gardées dans nos livres à Knob Lake sont: à tous les heures, "les températures, humidité, visibilité, nébulosité, direction et vitesse du vent, pression atmosphérique", Les totaux de la précipitation sont enregistrés tous les six heures ainsi que les observations du synoptique.

Nous faisons parvenir à Toronto (Service Météorologique Fédérale) toutes les données mentionnées ci-dessus plus les graphiques des feuilles du barographe et les feuilles diagrammes anémographiques pour le vent "direction et vitesse".

A Québec (Service Météorologique Provinciale) nous faisons parvenir les cartes pour les heures d'ensoleillements.

Il y a plusieurs items qui ne sont jamais publiés et que nous gardons à Knob Lake: la carte pour les pressions atmosphériques que nous faisons tous les matins à 0900Z en prenant la pression atmosphérique du niveau de la mer, la vitesse et direction du vent, la nébulosité des stations que nous recevons sur le télétype. On peut par ces données que nous insérons sur une carte climatologique voir où sont les basses pressions et les hautes pressions ainsi que leur direction. Par d'autres données que nous recevons, on ajoute sur la carte les courants d'air chaud et froid, etc., ceci est très utile pour les pilotes d'avions. Les graphiques des feuilles des thermographes, hygrographes, du réservoir qui enregistre les précipitations (Tipping Bucket rain gauge charts), les données du évaporomètre Livingston et black porous disc sont disponibles au Laboratoire ainsi que les statistiques de la neige et la glace (épaisseur), les données de température des screens de Dolly Ridge et de Ferriman Ridge qui sont situés à 300 et 900 pieds, à environs deux milles à l'est et quatre milles à l'ouest respectivement.

* M. Pelletier est un des observateurs à Knob Lake depuis Décembre 1965.

AN ANALYSIS OF THE 1964 SOLAR RADIATION RECORD AT THE BRACE EXPERIMENT STATION, ST. JAMES, BARBADOS

by

D. G. TOUT*

Introduction

Barbados, in latitude 13^{o}N, is situated approximately 100 miles to the east of the main arc of the Windward Islands. The Brace Experiment Station (fig. 1) is on the leeward coast of the island. To the east the ground rises in a series of terraces to the highest part of the island, reaching an altitude of 1,115 ft at Mt. Hillaby, and thence descends to the Atlantic coast through an area of more varied relief.

For most of the year Barbados lies in the zone of the Trade Winds which blow from directions between ENE and ESE in these latitudes. Only during the rainy season of June through November does the island occasionally come under the influence of the Intertropical Convergence Zone and synoptic-scale weather disturbances such as tropical storms.

The Brace Experiment Station of McGill University, on the St. James coast, was established to provide a base for experiments on solar energy and wind power utilization in a tropical environment with adequate incidence of solar radiation and wind speed. During the year 1964 the author was in residence at the nearby Bellairs Research Institute and undertook the task of hand-scaling the solar radiation charts to obtain hourly values for both total solar radiation (H) and diffuse, sky radiation (D) received on a horizontal surface. Values for direct solar radiation were obtained by subtracting the values for diffuse radiation

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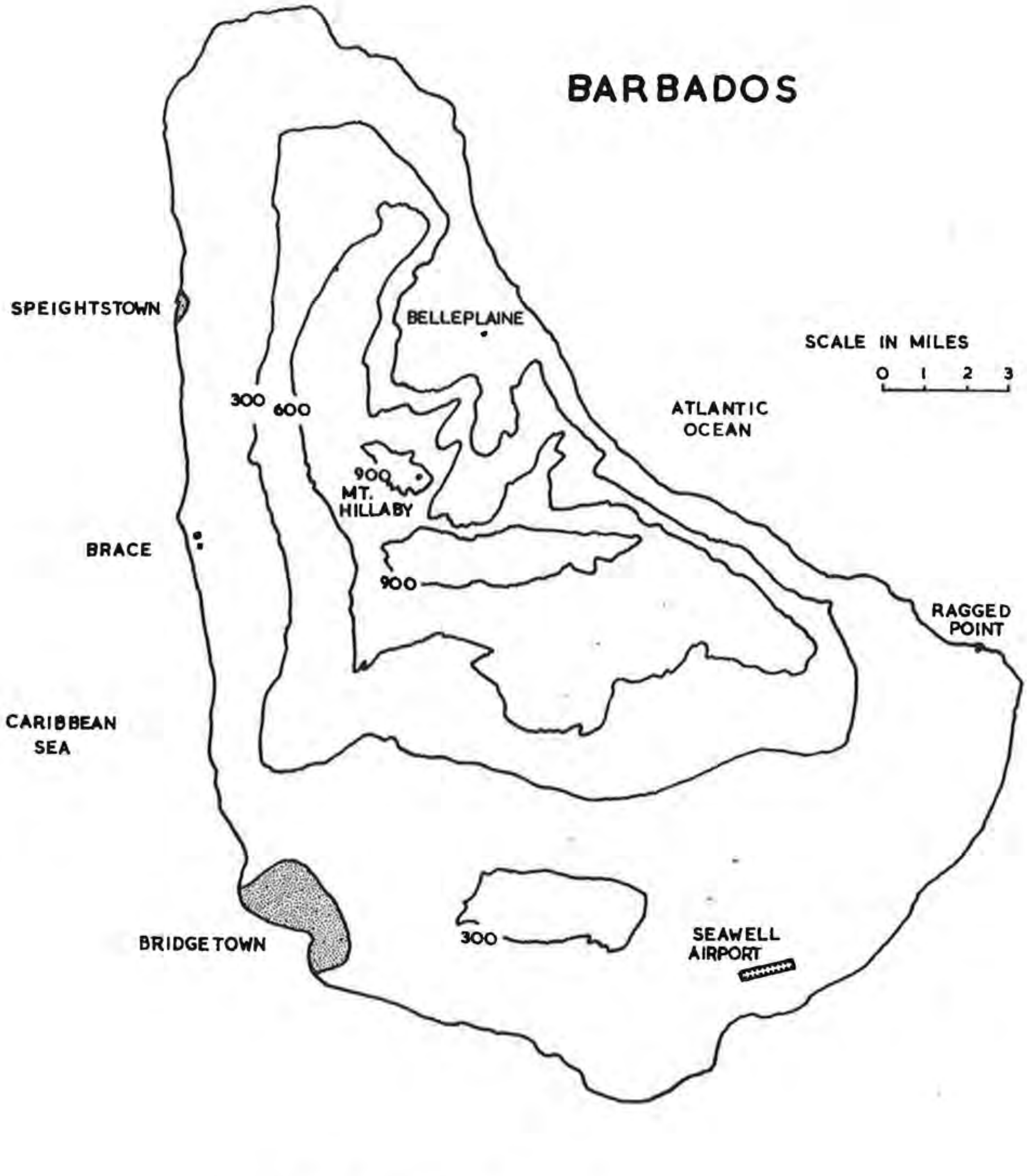

CONTOURS AT 300 FT. INTERVALS

Fig. 1. Location map of Barbados showing position of Brace Experimental Station.

from those for total radiation.

Instrumentation

Instrumentation consisted of both an Eppley and a Kipp pyranometer (fig. 2), but used at different times, for measuring the total radiation, and a silicon cell for measuring diffuse radiation. Both of these instruments were linked to Honeywell strip chart recording potentiometers to obtain a continuous chart record. The Brace radiation instruments were calibrated at Scarborough, Ontario, and the silicon cell at the station. To obtain the diffuse radiation record a shadow band was employed (fig. 2). This shadow band was reset, along the polar axis, to take account of the changes in declination of the sun. It was necessary to correct the measured values of diffuse radiation for the fraction of the radiation which was screened by the shadow band itself. The corrections were made for partly cloudy skies and theoretically derived for the 16th of each month.

A chart showing the degree of screening of the natural horizon was prepared and this indicated that on the average only 2% of the total radiation was affected by obstacles. The range of screening varied from a minimum of 1.75% on June 22nd to a maximum of 3.00% on December 22nd. Since this is within the range of error of the instruments and also the hand-scaling of the charts no corrections for screening have been made in this analysis.

The Monthly Radiation Record

Monthly radiation values for 1964 are shown in figure 3 and Table 1.

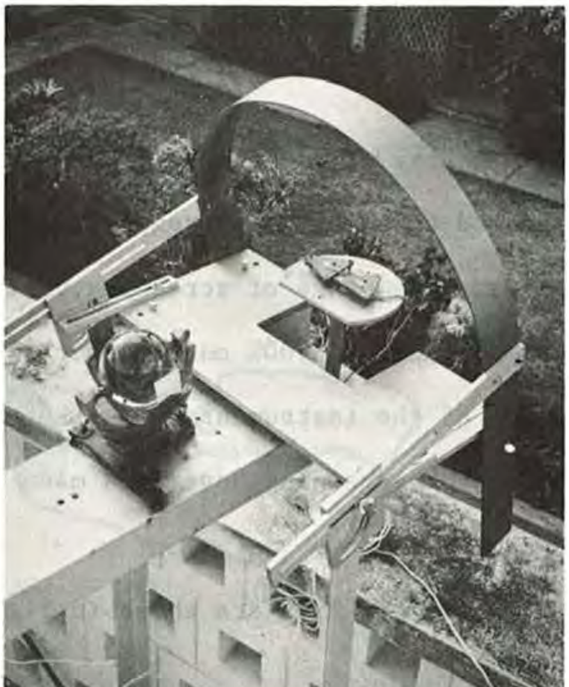

Fig. 2. Radiation equipment at Brace Experimental Station. Upper photo: Kipp solarimeter. Lower photo: shielded silicon cell, with Campbell-Stokes sunshine recorder nearby.

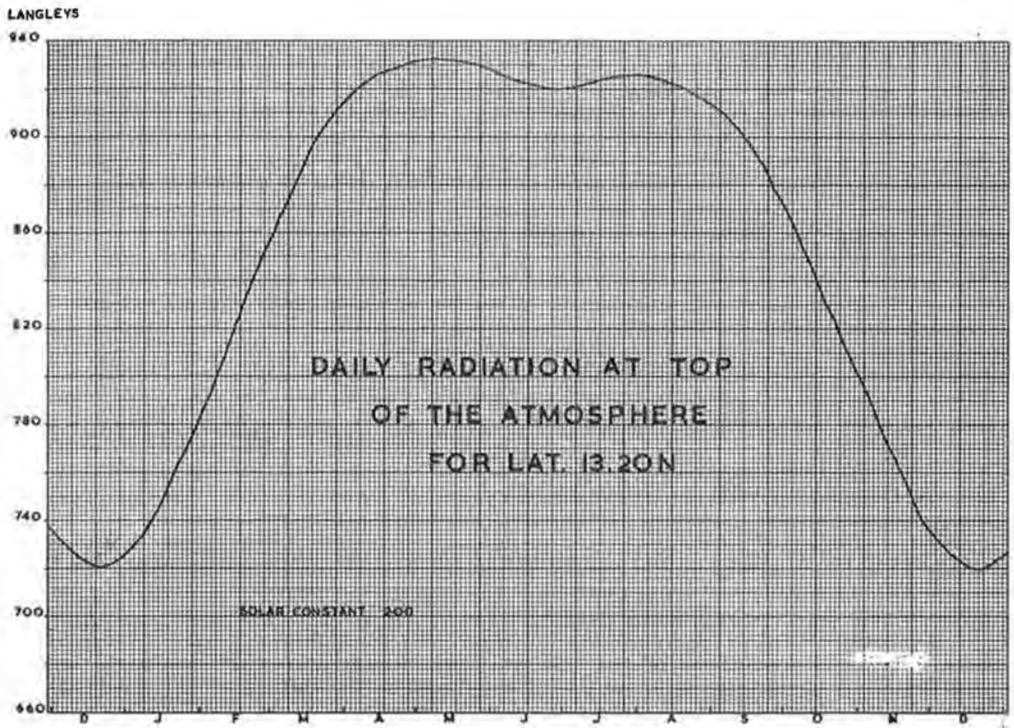

Fig. 3. Curve of monthly radiation at the top of the atmosphere for the latitudes of Brace Experimental Station.

TABLE 1

Mean Daily Radiation, 1964 (in langleys)

	Radiation at top of Atmosphere	Total Radiation	Diffuse Radiation	Direct Radiation	Percentage Diffuse	K_T
January	747	453	122	331	27	.61
February	818	475	159	316	33	.58
March	888	513	169	344	33	.58
April	925	509	212	297	42	.55
May	931	511	193	318	38	.55
June	922	449	204	245	45	.49
July	924	451	210	241	47	.49
August	922	478	187	291	39	.52
September	896	411	199	212	48	.46
October	836	442	160	282	36	.53
November	767	429	124	305	29	.56
December	724	432	114	318	26	.60

K_T, which has been called the cloudiness index (Liu & Jordan, 1960), is obtained by dividing the total radiation received at the surface (H) by the total radiation received at the top of the atmosphere (H_o). A K_T index of .60, therefore, means that 60% of the radiation incident on the top of the atmosphere actually reaches the surface of the earth. Figure 3 and Table 1 show that in the latitude of Barbados the daily average total solar radiation received at the top of the atmosphere varies little from 925 langleys (lys) for the five month period from April through August. On each side of this peak period values of H_o fall off rapidly to a low of 724 lys in the month of December. Values of H (fig. 4a), however, are far more uniform, reaching a peak of 511 lys in May (also the month of highest H_o values) and a low of 411 lys in September, a month which still receives 896 lys at the top of the atmosphere. An explanation may be found by considering the annual cloud régime. Cloud amounts increase during June at the beginning of the rainy season and remain at high levels until November. The months from December through May are less cloudy as Barbados experiences few cloud-producing weather disturbances such as easterly waves during this period. Values for $\overline{K}_T$ (fig. 4b) show that only 49% of the possible radiation, on average, is receive during the four months from June to September but 59% for the dry season months December to March. The decrease in H_o is, therefore, balanced by smaller cloud amounts to give a fairly uniform monthly distribution of H. The month of May with its low cloud amounts and high H_o values gives rise to the highest H values of the year.

Cloud is by far the most important element in determining the contribution by diffuse radiation. Thus, as the cloud cover increases so does the percentage of diffuse radiation making up the total. Diffuse radiation in November,

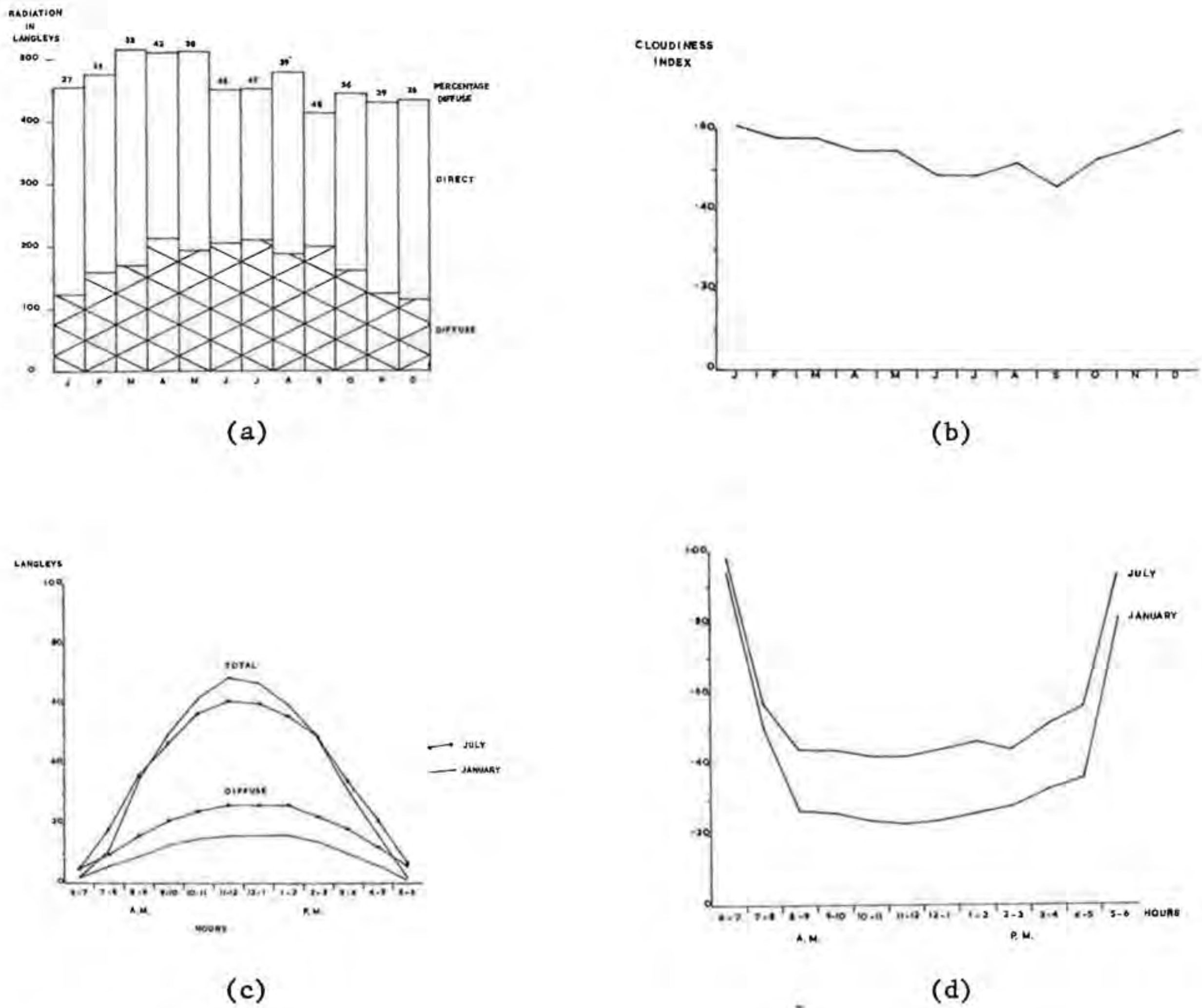

Fig. 4. Selected Radiation Data at Brace Experimental Station during 1964.

(a) Mean daily radiation each month
(b) Mean monthly cloudiness index
(c) Mean hourly radiation, January and July
(d) D/H ratio, January and July

December and January is less than 30%; by contrast, in June, July and September more than 45% of the total radiation is diffuse.

The Daily Radiation Record

Table 2 analyses the incoming radiation at Brace on a daily basis.

TABLE 2

Daily Total Radiation
at Brace Experimental Station, 1964

	Number of Days $H > 600$	Number of Days $H > 500$	Number of Days $H < 400$	Highest	Lowest
January	0	6	3	542	314
February	0	10	3	581	362
March	4	18	2	614	318
April	5	20	4	628	298
May	2	20	3	623	254
June	0	9	5	591	41
July	0	11	9	592	231
August	0	15	4	587	232
September	0	7	13	555	175
October	0	12	9	559	271
November	0	4	8	526	213
December	0	2	8	510	270
Year	11	134	71	628	41

Daily values in excess of 600 lys are confined to a three month period, March to May. These three months also record the greatest number of days with more than 500 lys. As mentioned above, these high values are due to the less cloudy skies preceding the rainy season. Days recording less than 400 lys exceed ten only in the month of September. Fifty-one out of seventy-one days occur in the second half of the year. Daily values of H less than 200 lys are very rare at the Brace Experiment Station and the unusually low minimum value of 41 lys in June (recorded on June 27th) was due to the heavy cloud and rain associated with a vigorous easterly wave.

Daily values of diffuse radiation are given in Table 3.

TABLE 3

Daily Diffuse Radiation
at Brace Experimental Station, 1964

	Number of Days D > 200	Number of Days D < 100	Highest	Lowest
January	1	10	227	67
February	5	2	251	77
March	8	2	237	90
April	18	0	319	112
May	13	1	314	84
June	16	1	282	41
July	17	0	283	145
August	10	1	266	90
September	13	0	278	107
October	6	1	275	94
November	0	6	169	84
December	1	12	200	70
Year	108	36	319	41

There are two sets of conditions under which very low totals of diffuse radiation may be recorded. Firstly, on a mainly cloudless day the absence of clouds will result in a low diffuse radiation total being recorded. An example of this type of day is January 22nd, 1964, when total solar radiation amounted to 525 lys and the diffuse element contributed only 67 lys. In the second case overcast conditions will give rise to a low value of total solar radiation, of which the greatest percentage will be diffuse. On June 27th, 1964, the supreme example of this latter type of day, the diffuse radiation accounted for 100% of the daily total radiation of 41 lys.

The Hourly Radiation Record

In most months the greatest hourly value of H occurs between 11 a.m. and 12 noon and the greatest hourly value of D one hour later (Table 4).

TABLE 4

Mean Hourly Values of H and D (in lys)

		A.M						P.M.					
Hours:		6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6
January	H	1.6	11.1	34.9	49.8	62.2	69.0	67.2	60.0	49.1	30.7	15.5	1.6
	D	1.5	5.6	9.4	12.8	14.7	15.6	16.3	15.8	13.6	10.2	5.6	1.3
February	H	2.8	17.3	36.3	53.5	65.0	70.5	67.4	62.4	49.0	32.8	15.3	2.1
	D	2.6	7.8	12.6	16.5	19.6	20.4	20.9	19.5	16.6	13.2	7.7	2.1
March	H	4.6	23.3	41.7	58.7	67.6	70.5	72.3	62.3	52.9	38.4	17.4	3.6
	D	3.3	8.6	12.5	17.1	20.3	22.2	22.6	21.2	18.6	13.7	8.9	3.4
April	H	6.6	21.4	39.9	56.5	66.1	71.4	70.5	61.1	51.3	38.3	20.5	5.7
	D	4.9	10.0	15.4	21.1	26.3	28.5	26.7	25.4	21.5	16.7	10.6	4.7
May	H	7.6	24.0	40.6	56.7	65.8	70.2	68.6	59.4	51.8	37.1	22.6	6.2
	D	5.9	10.8	15.3	19.4	22.0	23.6	24.0	22.0	18.9	15.3	10.4	5.1
June	H	6.0	19.9	34.2	45.1	58.3	62.7	62.9	55.1	44.6	33.4	19.9	6.9
	D	5.4	9.7	14.5	19.9	23.5	25.0	26.3	24.6	21.0	16.8	11.6	6.1
July	H	5.3	18.0	35.6	46.8	56.5	61.1	60.2	55.8	49.1	34.3	20.9	6.7
	D	5.2	10.3	15.5	20.5	23.9	25.5	26.4	25.6	21.5	17.6	11.8	6.2
August	H	5.7	21.9	37.7	54.1	58.7	64.3	65.0	58.8	49.8	37.0	19.8	4.9
	D	4.7	8.8	14.2	20.0	23.2	23.3	22.2	22.0	18.4	15.5	10.2	4.6
September	H	4.2	18.0	33.2	46.6	54.3	56.7	55.0	52.5	41.4	30.7	15.3	3.6
	D	3.8	8.1	14.7	19.5	24.4	25.1	24.9	24.7	22.2	16.6	11.0	3.6
October	H	2.6	16.7	37.3	51.4	60.3	64.0	62.0	54.8	43.9	32.9	13.1	2.6
	D	2.5	6.7	12.7	16.3	18.8	21.2	21.2	19.9	17.0	13.4	7.8	2.4
November	H	1.6	12.1	37.1	50.5	60.1	66.9	58.4	53.9	42.9	29.2	14.1	2.3
	D	1.3	4.9	9.0	12.0	13.6	15.8	16.5	16.3	13.9	10.5	7.5	2.3
December	H	1.1	7.5	33.8	49.6	63.0	64.8	59.7	55.2	47.6	32.3	16.1	1.9
	D	1.0	4.9	8.0	10.8	13.0	13.4	15.5	15.7	13.1	10.4	6.3	1.7

In figure 4c hourly data for January and July are plotted. It shows that in January hourly values for total radiation from 9 a.m. to 3 p.m. exceed those of July for the same hours, but that in the early morning hours and late afternoon period total radiation in July is greater than in January. In respect of diffuse radiation, however, no such difference is apparent: July figures exceed those of January for every hourly period.

The ratio of diffuse to total radiation (D/H), plotted in figure 4d, shows what percentage diffuse radiation contributes to the total for each hour of the day. The maximum percentage contribution is near sunrise and sunset since, with low solar elevations, much of the energy received is indirectly from the sky. In July values are higher than those of January for every hour. In July 44% of the total radiation is diffuse in the period between 8 a.m. and 3 p.m. while the figure for January during the same hour is 25%.

Daily Patterns of Radiation

Charts 1 - 7 (fig. 5) illustrate typical patterns of daily solar radiation and diffuse radiation in Barbados. The time scale of the charts is solar time and values of radiation, given in langleys (gram calories per square centimetre), are marked from left to right across each chart. The scale is from 0 to 2 langleys on charts 1 - 5, and from 0 - 1 langley on charts 6 and 7. Sunrise is near the bottom of each chart, and sunset near the top.

<u>Chart 1</u> - Instrument: Eppley 3861.

December 11, 1964 - total 491 lys. This chart represents an unusually clear dry season day with near clear skies until 1.40 p.m. after which clouds cross the sun at intervals until sunset. The sharp jump in the record at about 8 a.m. is due to the fact that prior to this hour trees intercepted the sunshine falling on the instrument. Note that the maximum intensity on such a day was 1.24 lys occurring just after 12 noon.

<u>Chart 2</u> - Instrument: Eppley 3861.

December 18, 1964 - total 502 lys. This chart illustrates a very frequent type of day both in the dry and wet seasons. After 9 a.m. light cumulus clouds interrupt the regularity of the curve. Intensity values fall to less than 0.2 lys during the passage of larger cumulus clouds. After 2 p.m. the sky becomes clearer.

<u>Chart 3</u> - Instrument: Eppley 3861.

December 29, 1964 - total 483 lys. The pattern shown on this chart is typical of the radiation characteristics associated with the presence of high clouds. These were particularly apparent between 8 a.m. and 11 a.m. on the day of the chart when a 6-tenths covering of cirrus was reported at 8 a.m., but only 1-tenth of cumulus. Days when cirrus type clouds predominate over the cumulus variety are rare in Barbados and so the pattern shown on Chart 3 is infrequently seen on the radiation charts.

<u>Chart 4</u> - Instrument: Eppley 3861.

January 1, 1965 - total 218 lys. This was an unusually cloudy day for the dry season over the whole island. The overcast sky reported at 8 a.m. continued for much of the day and little radiation was recorded anywhere on the island, e.g., Seawell Airport - 202 lys, and Mount Misery (an inland site) - 122 lys. These low totals were matched at Brace where the peaks and troughs merely represent variations in the density of the cloud sheet.

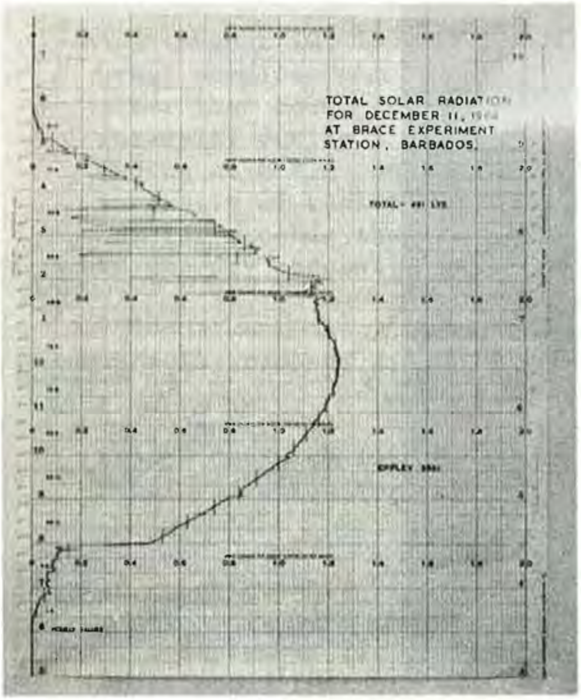

Chart 1. Total Solar Radiation, Dec. 11, 1964.

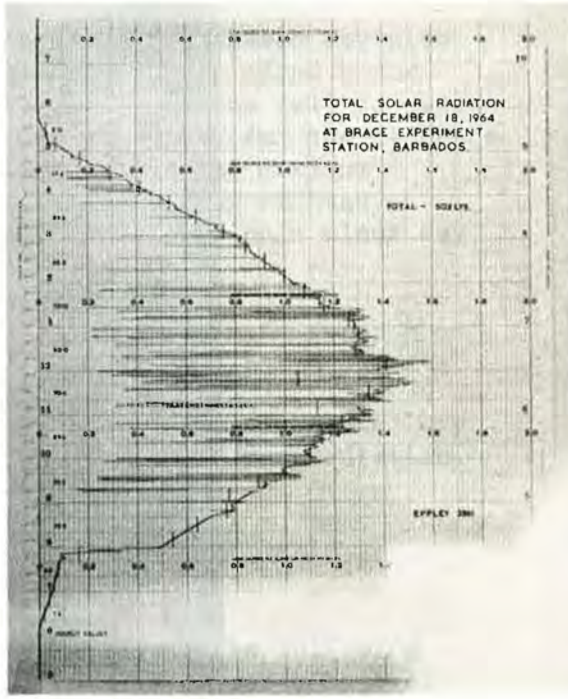

Chart 2. Total Solar Radiation, Dec. 18, 1964.

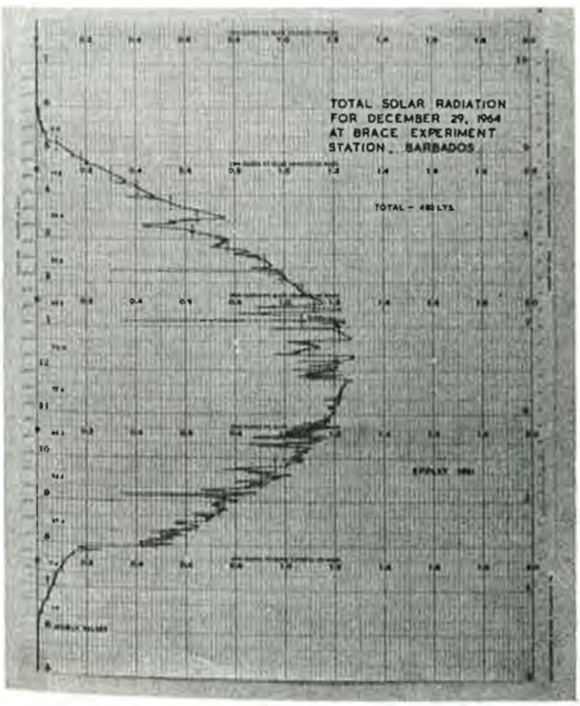

Chart 3. Total Solar Radiation, Dec. 29, 1964.

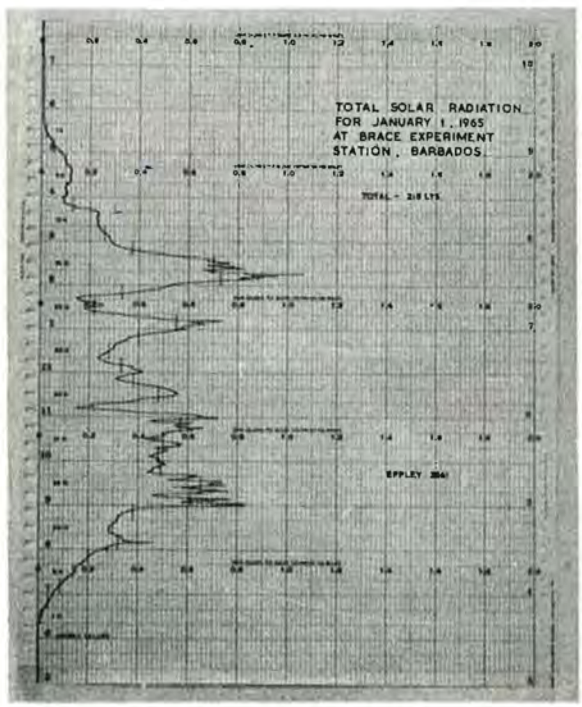

Chart 4. Total Solar Radiation, Jan. 1, 1965.

Fig. 5.

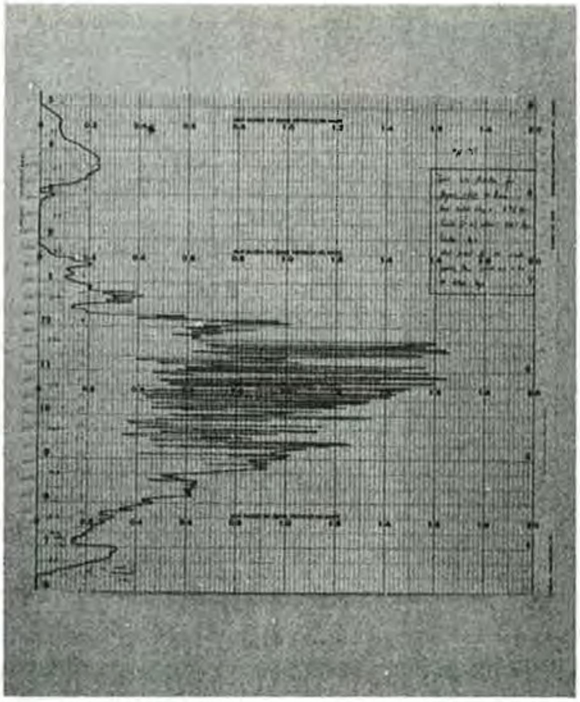

Chart 5. Total Solar Radiation, Aug. 10, 1964.

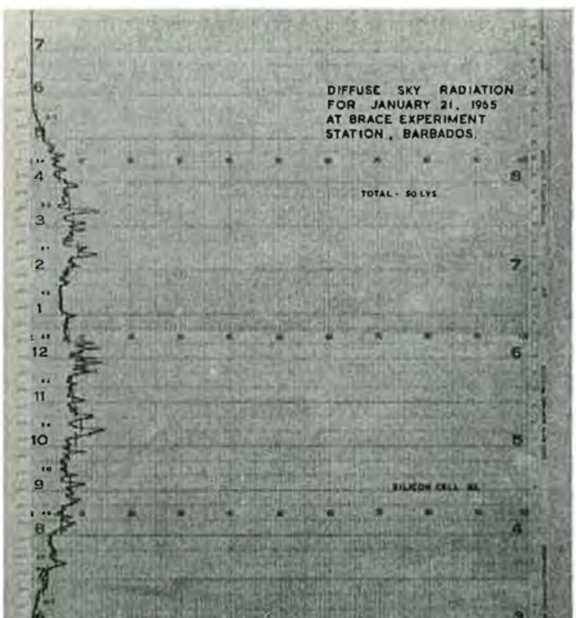

Chart 6. Diffuse sky radiation, Jan. 21, 1965.

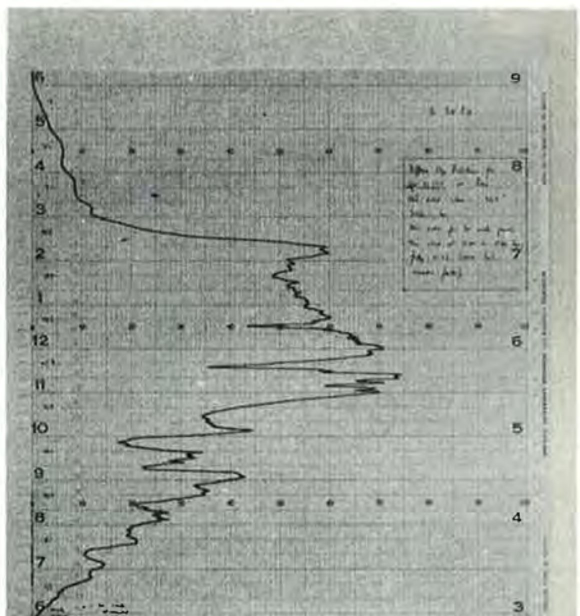

Chart 7. Diffuse sky radiation, Sept. 21, 1964.

Fig. 5 (cont.).

Chart 5 - Instrument: Kipp 1755.

August 10, 1964 - total 275 lys. This was a wet season day with heavy cumulus from 9 a.m. until noon and a more general cloud cover after that hour. Between 2 p.m. and 3 p.m. the radiation fell to zero intensity during a very heavy rainstorm (rainfall 0.94" for the 24 hours ending at 8 a.m. on August 11). Note, however, that the maximum intensity of radiation (1.66 lys) on this wet season day of heavy cumulus exceeds that recorded (1.24 lys on December 11) on a clear day in the dry season.

Chart 6 - Instrument: Silicon Cell B5.

January 21, 1965. Diffuse radiation 50 lys. A mainly clear dry season day with little cloud and, therefore, little diffuse radiation. Total radiation for the day was 515 lys.

Chart 7 - Instrument: Silicon Cell B4.

September 21, 1964. Diffuse radiation 260 lys. The following table shows that the diffuse radiation made up a large percentage of the total on this cloudy wet season day. Total radiation was 350 lys.

TABLE 5

Hourly Radiation for September 21, 1964

		A.M.		P.M.	
Hour:	9-10	10-11	11-12	12-1	1-2
Total Radiation	39.2	31.7	52.2	58.8	50.2
Diffuse Radiation	20.9	31.7	45.7	-44.3	38.4
Percentage of Diffuse in Total	54	100	88	75	76

Although based on only one year's data it is hoped that this study has given a useful insight into the annual march of solar radiation on the west coast of Barbados.

ACKNOWLEDGEMENT

The author wishes to thank the staff of the Brace Experiment Station for all the help given during the period of this study. Special thanks are extended to Dr. Austin Whillier, at that time Deputy Director of the Brace Experiment Station.

REFERENCE

B. Y. H. Liu and R. C. Jordan: "The Interrelationship and Characteristic Distribution of Direct, Diffuse, and Total Solar Radiation", Solar Energy, Vol. IV, No. 3, July 1960, p. 8.

A CHART FOR CALCULATING LONG-WAVE RADIATION

by

W. Bach*

A long-wave radiative chart (fig. 1) was developed in order to avoid lengthy calculations for the various components of incoming and outgoing infrared radiation under cloudless and cloudy conditions. For the calculation of the counter-radiation (G_L), and the effective outgoing radiation (S_L) under cloudless conditions only, the recording of dry bulb temperature (T_d) and wet bulb temperature (T_w) at screen level are necessary. From the former value the long-wave radiation emitted by the earth's surface can be calculated, while from the difference $T_d - T_w$ the vapour pressure (e) in millibars can be obtained.

In mid-latitudes the Brunt equation using Budyko's constants (Geiger, 1965, p. 20; Sellers, 1965, p. 56) gives the best results for the counter-radiation (G_L) under cloudless skies:

$$G_L = \varepsilon\sigma T^4(a + b\sqrt{e}) \text{ ly min}^{-1} \qquad \dots\dots\dots\dots (1)$$

where ε = coefficient of transmissivity assumed to equal 1

σT^4 = the Stefan-Boltzmann formula for longwave outgoing radiation

$\sigma = 8.26 \times 10^{-11}$; T is in ^oK

a,b = Budyko's constants being 0.61 and 0.05 respectively

e = vapour pressure in mbs.

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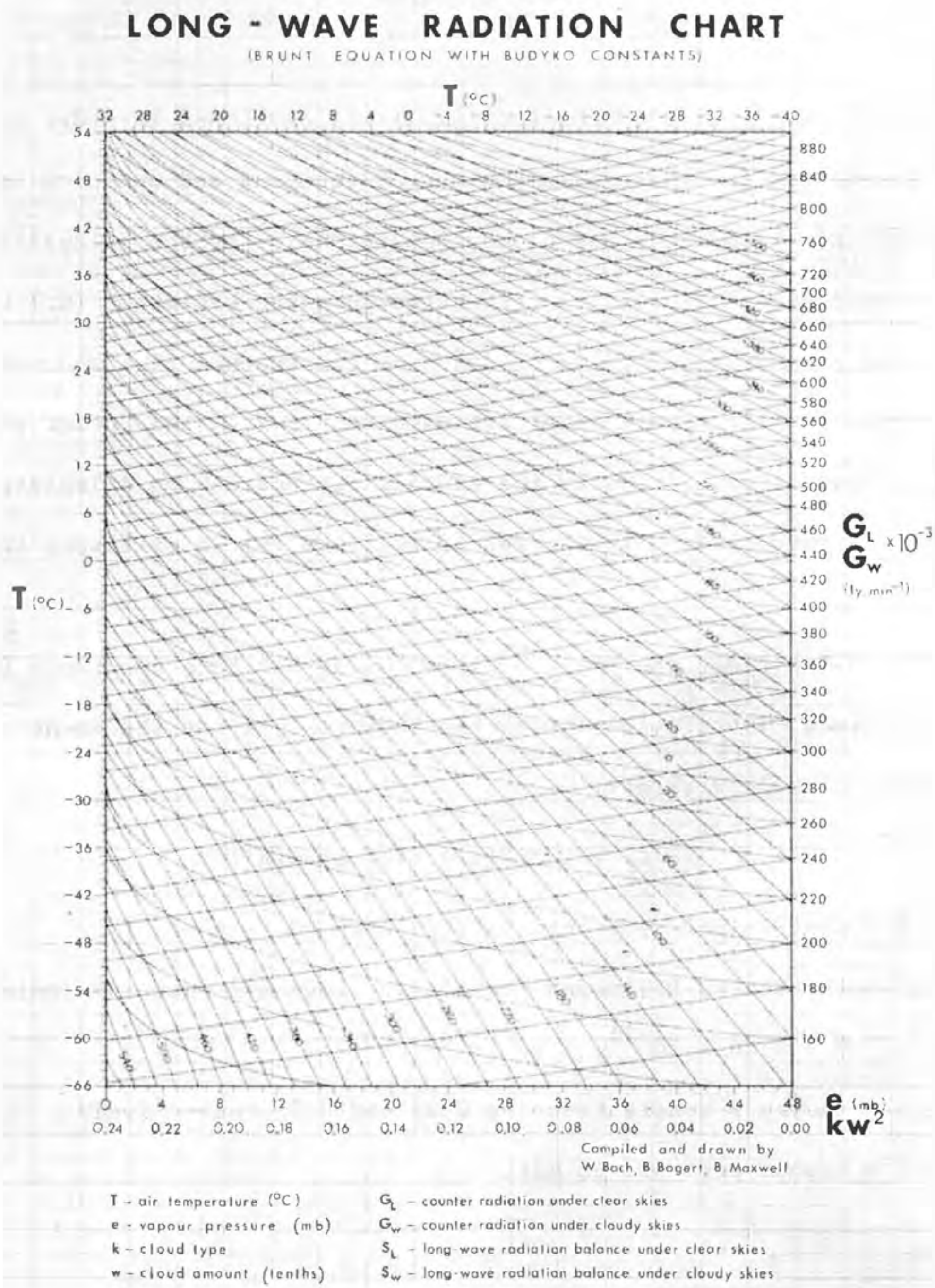
LONG - WAVE RADIATION CHART
(BRUNT EQUATION WITH BUDYKO CONSTANTS)
T (°C)
32 28 24 20 16 12 8 4 0 -4 -8 -12 -16 -20 -24 -28 -32 -36 -40
54 48 42 36 30 24 18 12 6 0 -6 -12 -18 -24 -30 -36 -42 -48 -54 -60 -66
T (°C)
880 840 800 760 720 700 680 660 640 620 600 580 560 540 520 500 480 460 440 420 400 380 360 340 320 300 280 260 240 220 200 180 160
G_L G_w $\times 10^{-3}$
(ly min^{-1})
0 4 8 12 16 20 24 28 32 36 40 44 48
e (mb)
0.24 0.22 0.20 0.18 0.16 0.14 0.12 0.10 0.08 0.06 0.04 0.02 0.00
kw^2
Compiled and drawn by
W. Bach, B. Bogert, B. Maxwell
T - air temperature (°C)
e - vapour pressure (mb)
k - cloud type
w - cloud amount (tenths)
G_L - counter radiation under clear skies
G_w - counter radiation under cloudy skies
S_L - long-wave radiation balance under clear skies
S_w - long-wave radiation balance under cloudy skies

Fig. 1.

An air pressure of 1015.9 mbs (30 inches) is assumed in all calculations.

From equation (1) it follows that the effective outgoing radiation or the long-wave radiation balance (S_L) under cloudless conditions is

$$S_L = \sigma T^4 - G_L \text{ ly min}^{-1}. \qquad \text{.......... (2)}$$

The Bolz equation for counter-radiation (G_W) under cloudy conditions is

$$G_W = G_L(1 + kw^2) \text{ ly min}^{-1} \qquad \text{.......... (3)}$$

where G_L = counter radiation under cloudless conditions

k = a cloud type constant

w = cloud amount in tenths.

The following cloud type constants are given by Geiger, 1965, p. 26:

Cloud type		k
St	=	0.24
As	=	0.20
Cu	=	0.20
Ac	=	0.17
Cs	=	0.08
Ci	=	0.04

Using the values obtained from equation (3) and the long-wave outgoing radiation (σT^4), we obtain the long-wave radiation balance (S_W) under cloudy conditions:

$$S_W = \sigma T^4 - G_W \text{ ly min}^{-1}. \qquad \text{.......... (4)}$$

The different stages involved in calculating the long-wave radiation balances under cloudless and cloudy conditions have all been assembled in one chart (fig. 1). The use of the chart is as follows:

<u>Step 1</u>: Find the temperature in $^{\circ}$C on the left-hand ordinate, take the relevant vapour pressure e (mbs) on the abscissa and follow the curved slanting line to read off the counter radiation (G_L) under cloudless conditions in the right-hand ordinate (values are in 10^{-3} ly min^{-1}).

Example: (a) $T = 10^{o}C$ $e = 10$ mbs $G_L = 0.4$ ly min^{-1}

(b) $T = 20^{o}C$ $e = 10$ mbs $G_L = 0.47$ ly min^{-1}.

The result in case (b) is interpolated by following the nearest curved line.

Step 2: Take the value obtained for G_L and the appropriate value for kw^2 and follow the line sloping upwards to the right and read off the value of the counter-radiation (G_W) under cloudy conditions on the right-hand ordinate, which also gives the G_L values (see equation (3)).

Example:

$G_L = 0.4$ ly min^{-1} $kw^2 = 0.12$ $G_W = 0.45$ ly min^{-1}.

The result is interpolated by following the nearest line sloping upward to the right.

Step 3: The procedure for finding the effective outgoing radiation (S_L) under cloudless conditions and its value (S_W) under cloudy conditions is essentially the same. Using the value obtained for G_L and G_W as the case may be, find its co-ordinate point with σT^4 which is given in ^{o}C on the top abscissa. From this point read off S_L or S_W by reference to the appropriate line sloping downwards from left to right on which is given the value of the effective outgoing radiation.

Example:

$G_L = 0.4$ ly min^{-1} σT^4 in $T^{o}C = 10^{o}C$ $S_L = 0.13$ ly min^{-1}

$G_W = 0.45$ ly min^{-1} σT^4 in $T^{o}C = 10^{o}C$ $S_W = 0.075$ ly min^{-1}.

By using the counter-radiation (G_L, G_W) and the effective outgoing radiation from the earth's surface (S_L, S_W) as read from the chart, the long-wave outgoing radiation from the earth-atmosphere system for cloudless ($G_L + S_L$) and cloudy ($G_W + S_W$) conditions can be easily obtained.

The accuracy of the values obtained from the chart as compared with those calculated on the computer is demonstrated by two examples:

Example 1:

given $T = +30^{o}C$

$e = 16$ mbs

$kw^2 = 0.04$

	G_L	G_W	S_L	S_W	(G_L+S_L)	(G_W+S_W)
			ly min^{-1}			
Calculated on Computer	0.563	0.575	0.132	0.121	0.695	0.696
Read off Radiation Chart	0.560	0.572	0.138	0.130	0.698	0.705
error	-0.003	-0.003	0.006	0.009	0.003	0.009

Example 2:

$$\text{given } T = 0^{o}C$$

$$e = 4 \text{ mbs}$$

$$kw^2 = 0.24$$

	G_L	G_W	S_L	S_W	(G_L+S_L)	(G_W+S_W)
			ly min^{-1}			
Calculated on Computer	0.325	0.403	0.133	0.054	0.458	0.457
Read off Radiation Chart	0.320	0.400	0.140	0.065	0.460	0.465
error	-0.004	-0.003	0.007	0.011	0.002	0.008

These two examples show that the counter-radiation (G_L, G_W) tend to be read slightly too low from the chart whereas the effective outgoing radiation (S_L, S_W) and the values of the long-wave outgoing radiation of the earth-atmosphere system are read off slightly too high from the chart as compared with calculations from the computer. On the whole, however, the errors are negligible.

A more detailed discussion on the value of the long-wave radiation chart, e.g. in agriculture, will be given elsewhere. It is obvious that this chart has great value in demonstrating to students the different kinds of infrared radiation components and their inter-relationships.

It is thought that a chart of this nature has not been prepared before. The active participation of the class in Advanced Climatology for the 1966-67 session at McGill University, and in particular of B. Bogert, B. Maxwell, and A. Ohmura, in the compilation and drawing of the chart are gratefully acknowledged.

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GENERAL CLIMATIC DATA

January, 1967.

	TEMPERATURE °F			PRECIP. Ins.		Sun-shine	Radiation
Date	Max.	Min.	Grass Min.	Snow	Rain	hours	lys day^{-1}
1	28.0	22.7	16.9	1.5	-	0.20	M
2	30.5	19.5	M	-	-	nil	M
3	33.9	28.4	25.4	TR	-	0.25	105
4	33.4	27.5	24.5	3.0	-	nil	33
5	28.2	0.0	-9.5	-	-	nil	41
6	9.1	-6.9	-19.5	-	-	7.30	238
7	36.5	0.4	M	1.5	0.01	0.70	94
8	33.1	21.4	17.0	-	-	nil	76
9	24.3	12.3	0.0	-	-	6.10	200
10	26.4	17.4	5.9	0.9	-	0.65	M
11	22.2	1.0	-0.3	-	-	0.35	M
12	30.1	2.9	M	2.3	-	nil	49
13	36.1	26.8	15.8	-	-	1.25	120
14	37.1	27.9	21.0	0.2	0.03	0.60	97
15	33.8	1.5	-2.2	0.3	-	nil	24
16	22.8	1.1	-19.0	0.2	-	7.55	M
17	31.2	-11.3	M	0.2	-	2.20	M
18	-3.2	-11.8	M	-	-	7.60	M
19	14.8	-5.1	M	-	-	4.30	163
20	26.2	10.9	M	0.3	-	nil	101
21	34.8	25.9	M	0.1	-	0.50	111
22	34.4	21.3	M	0.2	-	nil	77
23	34.3	21.1	M	-	0.13	1.55	11
24	38.3	18.2	M	-	-	0.55	96
25	43.7	32.2	M	-	0.39	1.15	75
26	33.3	10.5	M	-	-	nil	82
27	22.1	10.2	M	7.0	-	nil	34
28	20.3	15.2	M	1.0	-	0.60	94
29	18.2	8.0	M	-	-	0.60	133
30	16.4	6.0	M	-	-	7.80	221
31	19.5	9.0	M	-	0.40	7.95	222
Month	26.0	11.7		18.7	0.96	59.75	104

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GENERAL CLIMATIC DATA

February, 1967.

Date	TEMPERATURE °F Max.	Min.	PRECIPITATION Ins. Snow	Rain	Sun-shine hours	Radiation lys day^{-1}
1	28.8	15.0	-	-	nil	M
2	M	-4.5	-	2.90	nil	45
3	M	-2.9	-	-	8.05	177
4	30.8	17.8	-	2.80	nil	117
5	M	-12.9	-	-	5.45	145
6	M	-11.2	-	-	8.25	212
7	M	-12.0	-	-	0.30	M
8	M	6.5	-	0.70	6.45	M
9	M	9.4	-	0.40	1.10	92
10	31.5	19.8	-	-	2.95	M
11	33.8	-24.0	-	2.00	0.70	67
12	-10.9	-24.9	-	-	8.50	57
13	9.6	-10.0	-	-	8.60	352
14	22.0	9.1	0.7	-	nil	75
15	M	9.8	2.7	-	1.60	157
16	M	3.1	1.0	-	1.80	29
17	M	-10.0	-	-	8.60	M
18	3.3	-4.3	-	-	8.20	309
19	11.9	-5.5	0.4	-	8.70	M
20	23.7	11.3	2.6	-	nil	53
21	18.0	0.3	0.5	-	nil	M
22	32.4	7.9	-	-	7.50	M
23	30.2	M	3.0	-	nil	M
24	M	-4.4	-	-	2.30	247
25	9.0	-2.2	-	-	7.20	337
26	13.1	2.5	-	-	9.05	370
27	27.9	12.8	3.0	-	4.00	304
28	M	M	2.5	-	nil	39
Month	19.7	-0.8	16.4	8.80	109.30	168

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GENERAL CLIMATIC DATA

March, 1967.

Date	TEMPERATURE °F Max.	Min.	PRECIPITATION Ins. Snow	Rain	Sun-shine hours	Radiation lys day^{-1}
1	11.5	-1.8	-	-	8.95	M
2	25.4	6.1	-	-	2.20	226
3	37.8	5.1	0.2	-	1.55	239
4	17.9	1.1	-	-	9.10	373
5	23.3	16.5	0.5	-	2.05	243
6	29.7	18.9	-	-	3.55	261
7	31.0	M	-	-	0.20	205
8	M	M	-	-	9.20	330
9	33.9	M	-	-	9.20	354
10	41.3	30.3	-	-	2.30	255
11	40.5	6.3	-	-	nil	121
12	22.5	7.1	-	-	9.60	387
13	34.4	21.1	0.8	-	nil	72
14	31.1	20.4	-	-	4.50	294
15	26.0	10.0	-	-	7.40	416
16	17.2	-3.7	-	-	6.75	390
17	11.6	-7.4	-	-	9.15	427
18	7.2	-5.0	-	-	9.40	444
19	25.6	4.9	0.4	-	9.15	441
20	30.6	13.0	-	-	7.20	337
21	34.7	21.9	0.8	-	3.75	343
22	34.8	22.3	-	-	1.80	291
23	34.8	21.0	-	-	6.60	382
24	38.2	23.8	-	-	4.15	404
25	36.2	24.0	-	-	10.20	476
26	42.8	26.1	-	0.30	10.20	501
27	M	M	-	-	3.20	M
28	42.2	33.3	-	-	nil	167
29	46.8	20.6	-	-	8.55	437
30	42.8	24.0	-	-	9.40	476
31	50.1	41.4	-	TR	9.35	440
Month	29.8	14.9	2.7	0.30	181.65	336

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GENERAL CLIMATIC DATA

April, 1967.

Date	TEMPERATURE °F Max.	Min.	PRECIPITATION Ins. Snow	Rain	Sun-shine hours	Radiation lys day^{-1}
1	61.6	41.4	-	-	M	400
2	52.3	38.9	-	0.40	6.85	339
3	40.8	12.3	-	-	3.95	221
4	40.0	17.4	-	-	9.60	434
5	49.1	23.5	-	-	1.15	129
6	33.2	24.6	0.04	-	nil	146
7	33.1	24.9	0.05	-	nil	104
8	46.3	30.3	-	-	8.80	451
9	58.0	40.7	-	0.55	8.85	438
10	41.7	M	-	-	4.15	294
11	31.7	13.0	-	-	11.35	586
12	38.5	18.4	-	-	11.25	573
13	M	M	-	M	M	577
14	53.9	37.3	-	0.21	M	446
15	45.9	34.3	-	0.34	nil	94
16	58.0	31.1	-	TR	nil	101
17	51.1	M	-	0.45	1.30	239
18	41.1	30.2	-	-	nil	57
19	45.7	29.8	-	-	1.00	M
20	47.1	28.9	-	-	10.30	M
21	50.0	36.9	-	0.23	8.10	483
22	60.9	34.6	-	0.39	1.90	83
23	44.4	34.0	-	-	0.80	154
24	45.9	28.1	-	-	3.90	314
25	45.8	28.2	-	-	11.00	625
26	54.0	31.5	-	-	12.20	634
27	52.9	31.0	-	-	12.40	641
28	M	M	-	-	12.50	643
29	M	M	-	-	12.40	643
30	54.0	30.0	-	-	12.40	637
Month	47.3	29.3	0.09	2.57	188.15	375

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GENERAL CLIMATIC DATA

May, 1967.

Date	TEMPERATURE °F Max.	Min.	Grass Min.	Dew Point	Rain Ins.	Sun-shine hours	Radiation lys day^{-1}
1	78	55	M	M	-	12.4	607
2	74	54	49	43	0.31	6.0	316
3	49	41	M	44	0.15	1.2	143
4	51	30	24	24	-	9.6	540
5	48	35	32	38	-	11.3	452
6	63	27	17	M	-	12.8	667
7	57	32	23	27	0.34	6.2	412
8	39	31	30	31	-	nil	191
9	42	33	30	34	0.48	nil	111
10	50	31	M	35	0.09	0.8	178
11	48	31	26	33	0.17	1.6	269
12	53	33	M	M	-	10.2	642
13	55	34	31	24	-	11.2	664
14	54	35	32	42	-	13.0	683
15	47	43	34	39	0.22	nil	74
16	49	35	34	27	-	6.1	354
17	61	36	29	35	0.03	5.4	358
18	58	36	29	28	0.27	4.2	398
19	66	43	43	50	0.18	1.1	79
20	57	46	40	43	0.13	6.2	323
21	51	34	30	26	-	M	394
22	52	35	30	30	-	M	568
23	58	35	25	38	-	12.4	647
24	66	41	33	37	-	13.1	587
25	56	48	44	36	-	0.2	268
26	60	41	40	31	-	8.0	M
27	59	40	38	35	-	7.5	M
28	63	45	45	41	-	11.5	M
29	62	44	40	25	-	8.3	M
30	62	41	31	26	-	13.4	563
31	65	49	40	34	-	9.5	655
Month	56	38	34	34	2.37	203.2	413

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GENERAL CLIMATIC DATA

June, 1967.

Date	TEMPERATURE °F Max.	Min.	Grass Min.	Dew Point	Rain Ins.	Sun-shine hours	Radiation lys day^{-1}
1	77	48	37	45	-	12.3	505
2	82	60	48	45	-	12.9	655
3	85	56	48	51	-	13.6	659
4	M	M	51	M	-	13.6	672
5	84	62	53	57	-	13.0	634
6	79	62	58	57	-	3.8	357
7	76	52	50	58	0.32	1.3	M
8	72	54	M	46	0.43	6.3	M
9	81	61	M	61	-	6.8	M
10	77	56	52	65	-	6.3	346
11	71	57	52	M	0.18	3.3	370
12	60	49	48	M	TR	0.6	229
13	72	52	M	M	0.15	8.9	632
14	63	53	53	M	0.32	nil	65
15	79	59	58	M	0.16	1.4	230
16	81	68	63	M	1.02	6.8	377
17	62	60	60	M	0.69	nil	83
18	68	56	52	47	-	11.8	717
19	67	48	43	40	-	11.8	707
20	72	51	42	42	-	9.3	650
21	75	54	54	57	-	5.0	487
22	69	63	60	65	0.59	M	610
23	77	57	54	64	-	M	428
24	77	52	52	59	0.09	10.0	423
25	73	63	M	65	0.09	3.6	192
26	73	62	M	52	-	11.9	661
27	77	56	50	56	-	10.9	692
28	81	55	53	58	-	11.9	694
29	73	61	55	57	-	6.6	460
30	69	60	M	M	-	1.5	443
Month	74	57	52	55	4.04	205.2	481

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