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SOME PROBLEMS IN LARGESCALE MAPPING OF THE TOPOGRAPHIC VARIATION OF SOLAR RADIATION

by

B. K. BASNAYAKE*

Energy, that powers all natural processes on land, sea and air, is supplied largely by the sun, in the form of shortwave radiation. The increasingly active realisation, in recent years, of the importance of this solar radiation for earth processes has led to an increasing emphasis on the study of solar radiation income, not only in meteorology where it has been traditionally studied, but also in the other earth sciences as well. These sciences use the quantitative pattern of solar radiation income on the earth surface as the input energy field, in considering the energy transformations relevant to their respective fields of study. It is, therefore, important to develop accurate ways, to make large scale maps of the distribution of solar radiation income over the earth.

It is theoretically possible to make distribution maps of solar radiation income in two ways: by computation from fundamental principles or by using the data of observational networks. The availability of high speed electronic computers has made basic computation practical. However, in the present state of the science of solar radiation income, the understanding of natural laws, especially those relating to the atmosphere, is inadequate to

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obtain satisfactory results by this method alone. A network of radiation measuring stations, sufficiently elaborate in relation to the actual complexity of solar radiation income distribution, can provide the basic data for mapping. The present network of solar radiation measuring stations is, however, somewhat sparse. Even in the scientifically advanced countries of Western Europe and North America, the network of actinometric stations is inadequate in relation to the variability and complexity of the actual distribution of solar radiation income. In practice, therefore, solar radiation distribution is mapped by combining the two methods: theoretical formulae, partly based on well understood laws, but partly empirically derived to cover certain ill understood aspects, are combined with measurements of solar radiation and related data from the available network of stations to produce fairly satisfactory results.

The receipt of solar radiation at a point on the earth's surface is a function of three factors: the extra-terrestrial solar radiation intensity,depending primarily on earth-sun distance and the latitudinal position of the point on the earth; depletion of solar radiation intensity by passage through the atmosphere, at the same time contributing a diffuse component to the surface, depending on the thickness of the atmosphere along the beam path, and the amount of absorbtion, reflection and scattering within it; and the geometrical attitude of the earth surface to the angle of incoming radiation. The first and third of these factors are easy to calculate since they depend on relationships which can be expressed in simple mathematical form in terms of direct beam radiation and topographic shapes. The second factor, which comprises atmospheric transmissivity,is difficult to calculate accurately and is usually measured.

Many computations and mapping of solar radiation income have been made without taking topographic effects into account. In nearly all small scale maps of surface distribution of solar radiation intensity, the values are represented as that received on a horizontal surface, the elimination of topographic influence being considered desirable in the resultant simplicity of pattern. Likewise, measurement of solar radiation is mostly done on a horizontal surface so as to make the results representative of a wide surrounding area. However, the inaccuracy resulting from ignoring the topographic influence, which is high in areas of even moderate relief, especially with low sun angle as in winter or in the early morning or late afternoon hours, while possibly acceptable on small scale maps, is intolerable on large scale ones.

Early attempts at the evaluation of solar radiation receipt on slopes are the work of Kimball (1922) and Garnett (1935). More recently, the work of Kondratyev and Manolova (1960), and Heywood (1964) are important. One of the most recent publications on the subject is that of Garnier and Ohmura (1968, 1970). The last is a combination method of part computation and part observation. The computation makes maximum use of the simplicity of geometrical relations of the direct-beam solar radiation and attitude of the topographic surface, but substitutes direct observation of the diffuse component when its computation becomes too complex. It is versatile enough to be applicable to any part of the world, and for obtaining values of a few minutes to those for a day.

The basic formula used by Garnier and Ohmura (1970) is as follows:

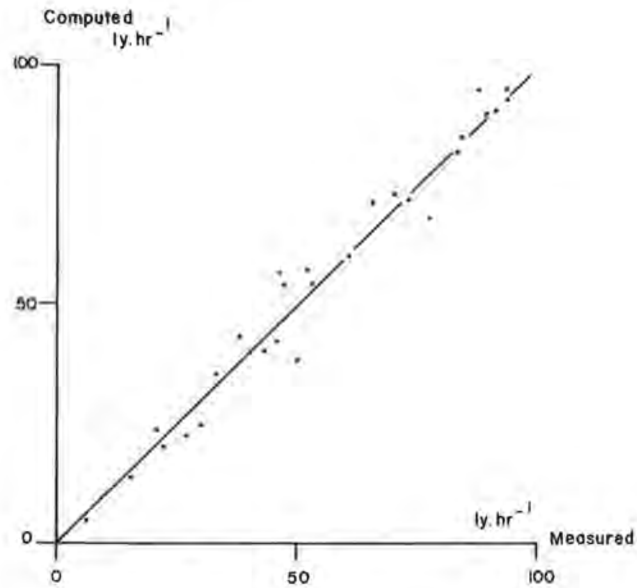

Fig. 1. Comparison of Computed and Measured Global Radiation Values in Barbados

$$I_s = I_r p^m \cos(\underline{x} \wedge \underline{s}) + D_h \cos^2 \frac{\theta}{2} \quad (1)$$

where

- I_s = intensity of shortwave radiation in ly min^{-1} falling on a surface
- I_r = value of extra terrestrial radiation equal to the solar constant divided by the radius vector squared of the earth
- p = mean zenith-path transmissivity of the atmosphere
- m = optical air mass
- $\underline{s}$ = unit coordinate vector expressing the position of the sun
- $\wedge$ = angle between $\underline{x}$ and $\underline{s}$
- D_h = diffuse radiation recorded on a horizontal surface
- θ = elevation angle of surface
- $\underline{x}$ = unit coordinate vector normal to the surface

The accuracy of the computation has been tested against measured values at Mont St. Hilaire, Quebec where computed values were found to be generally within 3% of measured values (Ohmura, 1969). Similar tests carried out in Barbados reveal an accuracy of within 5% at the hourly level for computed against measured values. Results from the latter tests are illustrated in fig. 1. The slope of the regression line in this figure is given by

$$y = 00.00 + 1.01x$$

and there is a correlation coefficient of $r = 0.982$ for the data.

In mapping the topographic variation of shortwave solar radiation of a given area, an appropriate base map must first be obtained. A good topographic map of suitable scale with clearly marked contours is excellent for the purpose. A preliminary step is to make sure that the degree of detail of the computation of topographic variation of solar radiation agrees with the amount of topographic detail available on the base map. In the example given here, the Barbados 1:10,000 topographic (British Directorate of Colonial Surveys, 1953) with a contour interval of 20 feet, was matched with computed topographic changes in solar radiation under variations of 2° gradient and 5° azimuth intervals.

The next step is to measure slopes on the selected topographic map. As slopes are very variable in most natural landscapes, the adoption of some sampling method is essential. In previous maps of topographic variation of solar radiation (Garnier & Ohmura 1968; Basnayake 1968) slopes were sampled at intersection points of a superimposed grid. Allowance was made for

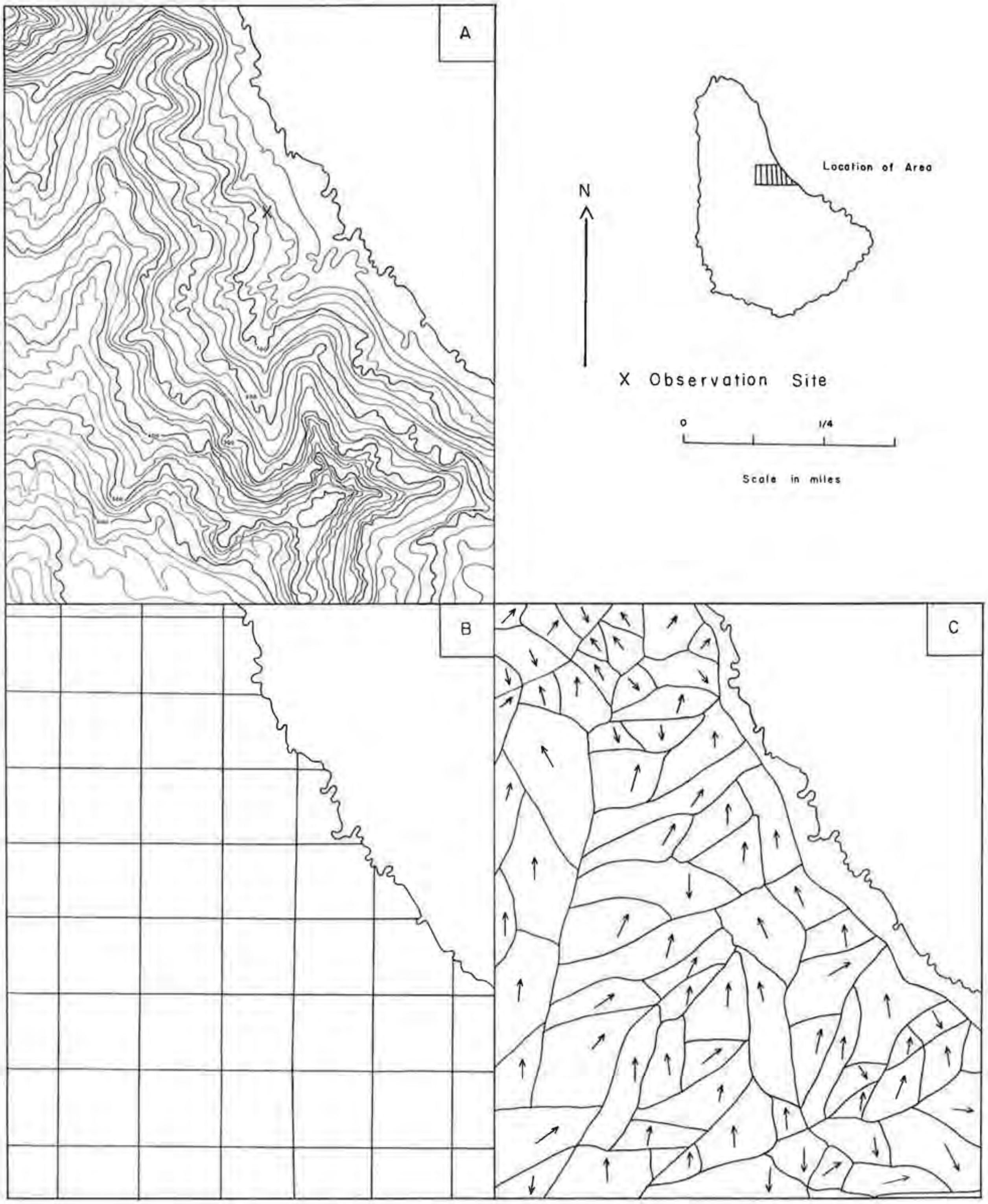

Fig. 2 Methods of Relief Analysis, East Coast, Barbados.

differences in topographic complexity by varying the size of the grid. The size of the grid pattern to be used for an area of complicated relief, may be determined by plotting the average gradient and azimuth of a small representative area, successively doubling the number of sampling points, and noting when the relationship levels off. In the hilly eastern part of Barbados a stable value of 25 sampling points per 10 cm. square was obtained on a map of 1:10,000 scale and 20 foot contour interval, (Basnayake 1968). The maps appeared to be satisfactory in the reduced scale published, but the accuracy of detail that was potentially available in the large scale base map was not realised. In the grid method, the assumption is that slopes on the topographic map vary at random. However, observation shows that, in most areas of the world, slopes do not vary completely at random, but are more or less organised into facets of comparatively uniform gradient and azimuth, and bounded by fairly well marked strips where gradient and azimuth vary rapidly. Ridge, valley and spur axes, forming the boundaries of such slope facets, are easily recognized. Fig. 2a shows the relief of a hilly area adjacent to the east coast of Barbados, and figs.2b and 2c indicate the application of the 'grid' and 'slope facet' method respectively.

To measure the gradient of the slope in each 'slope facet' area, the number of successive contour lines over standard distance was used rather than the difference between individual adjacent contours. This procedure was followed for two reasons: it is easier to count the successive contours over a comparatively large pre-determined standard distance than to measure accurately small distances between two contours; and to use a standard distance for gradient measurement enables an average value to be obtained that takes into account the area around a sampling point, rather than using the value at a given single point. A circle 15 mm in diameter was used for gradient analysis. This proved to be an optimum size which avoided both the ambiguity of single contour interpretation arising from the use of a smaller circle, and the difficulty of determining average slope direction and counting too many contours if a larger circle were used.

The 1:10,000 maps used to prepare the base map had contours on them at 20 ft. intervals. For such a map therefore, the number of contours in a 15 mm distance corresponding to different angles is given by

$$y = \frac{15 \tan x}{0.610} \tag{2}$$

where x is the given angle of slope and y the number of contour crossings in 15 mm of map distance.

The calculation of the values of azimuth and gradient to be inserted in each 'slope facet' was effected by means of a clear plastic protractor, with a movable pointer of semi-rigid plastic pivoted at the origin of the protractor. The pointer was marked with a central longitudinal line, with another at right angles to it and passing through the pivoted origin. A circle of 15 mm diameter, with its centre at the pivoted origin, was also marked on the pointer. The protractor, with the pointer attached, was placed in the centre of a 'slope facet'. To obtain the azimuth of the slope, the pointer was moved, so that its marker line was perpendicular to the major contour trend, and the appropriate angle was then read on the circular margin of the protractor. For gradients, it was simply necessary to count the successive contours within the 15 mm circle and to read the corresponding gradient from the values in a table prepared from equation (2).

To effect the mapping of global radiation by using the base map prepared in this way, a computer programme (Garnier & Ohmura, 1969) was made which calculated the value of the global radiation for each hour of the required date for gradients from 0 to 40° in steps of 2 deg. and all azimuths in steps of 5 deg. This calculation was made using global and sky-diffuse radiation on the standard horizontal plane at the representative site shown in fig 2a. The computed values of global radiation for each 'slope facet' whose azimuth and gradient has been measured previously, was then read off and inserted on the base map, and equiradiation lines drawn. The resultant maps, for 0700 to 0800 hrs on the 22nd of September, 1969 are shown in figs. 3a (using the grid method of topographic sampling) and 3b (using the slope facet method). It is clear that map 3b brings out more detail, and is topographically much more realistic.

In some applications of quantitative estimates of global radiation, the areal distribution of global radiation is of interest. For example, the well known combination equation of Penman (1948) and also the use of the Bowen ratio for estimating evapotranspiration use net radiation as the critical parameter, and it has been shown that net radiation itself is correlated strongly with global radiation (Shaw 1956, Monteith and Szeicz, 1962, Fritschen 1967). Thus, a map of the topographical variation of global radiation may serve to indicate the areal distribution of potential evaporation of watersheds, which would be useful in forestry, hydrology and agriculture.

Maps of topographical variation of global radiation, such as those illustrated in fig. 3 may be interpreted to give quantitative areal estimates. Such estimates must be carried out with care, with due attention paid to the fact that the conventional topographic map does not depict true slope surface

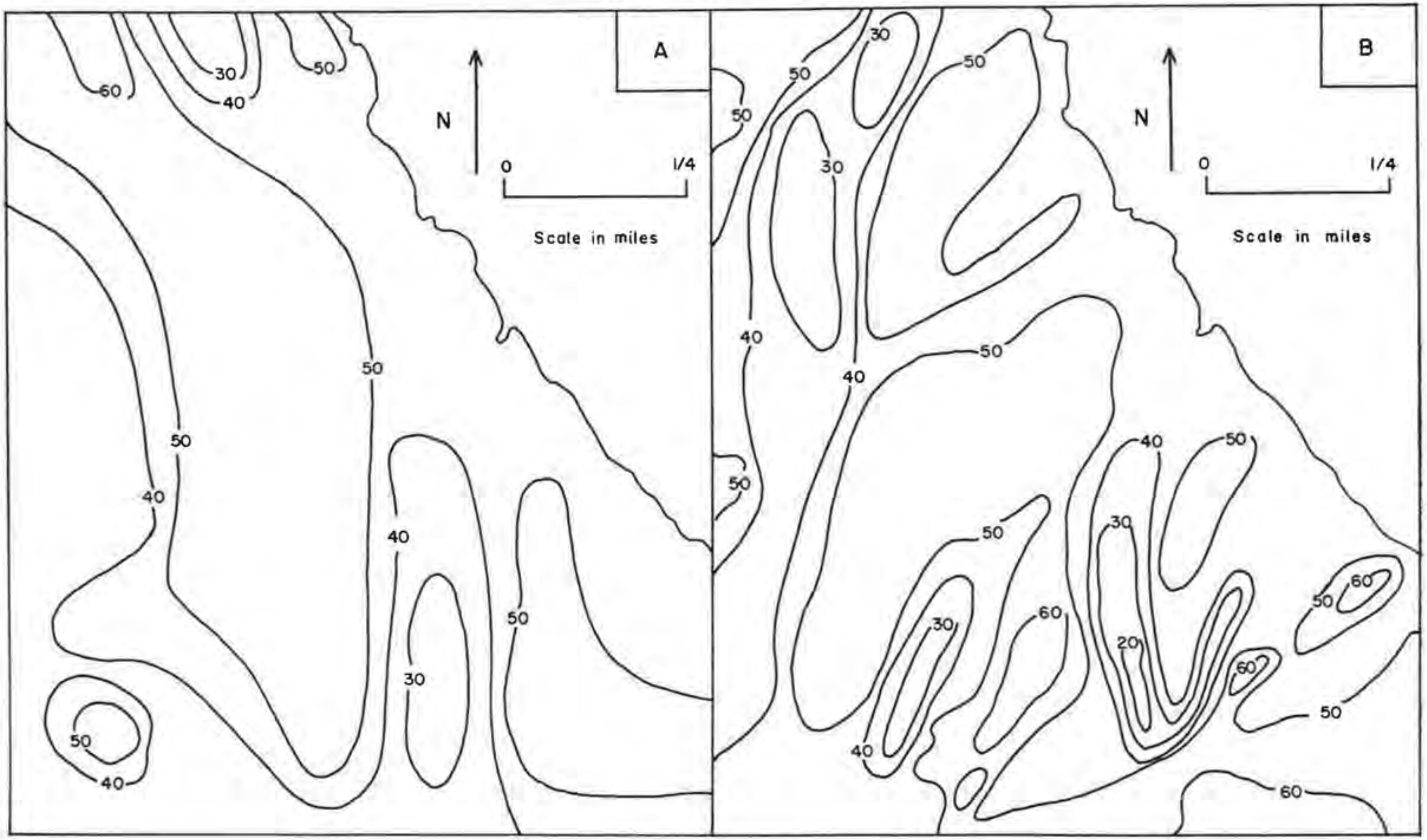

Fig. 3 Comparison of Grid Method (A) and Slope-facet Method (B) of Mapping Global Radiation

area, whereas the computation of topographic variation of solar radiation intensity is generally made in units per slope area. Thus, direct areal measurement of the global radiation heat load on an area cannot be carried out directly from maps like those in fig. 3.

Theoretically, the problem can be overcome in two ways; either by adapting the topographic map to show true slope area, or by changing the computed values of solar radiation in proportion to the difference between the true slope area, and that given by the conventional map. The first is impractical because such maps are not easily made, and even if they were available, direction and shape on them will be so distorted as to make them difficult to read. The latter solution is simpler. Slope area on the conventional map is represented by its projection on the plane of sea level. The relationship between true slope area and its sea level plane projection is given by the inverse cosine function. An examination of the variation of the cosine function (Table One) shows that the difference is significant for slopes steeper than 10°. However, if the computed topographic variation of global radiation intensity is multiplied by the 1/cos of the gradient angle the result will be to give a 'map radiation unit'. The effect given by such a procedure is indicated in Table Two, and the results for pre-noon hours on two dates are illustrated in figs. 4 and 5 for the east coast of Barbados. These maps may be planimetered directly to give areal quantitative estimates of global radiation.

TABLE ONE

Gradient °	Map slope area projected on sea-level plane (cosine function)
10	.98
15	.97
20	.94
25	.91
30	.87
35	.82

TABLE TWO

Global Radiation Income at Cambridge Plantation, Barbados, for Slope 18° (gradient) and azimuth 90° East

		Measured I_s	Computed I_s	Computed $I_s/\cos\alpha$
22nd Sept. 69	9700-0800 hrs.	54 ly	58 ly	61
	0800-0900	73	76	80
	0900-1000	91	99	104
	1000-1100	93	97	102
	1100-1200	23	24	25
23rd Sept. 69	0700-0800 hrs.	52 ly	61 ly	65
	0800-0900	61	64	68
	0900-1000	93	100	105
	1000-1100	66	68	72
	1100-1200	51	42	44

I_s = Global Radiation Intensity α = slope gradient angle

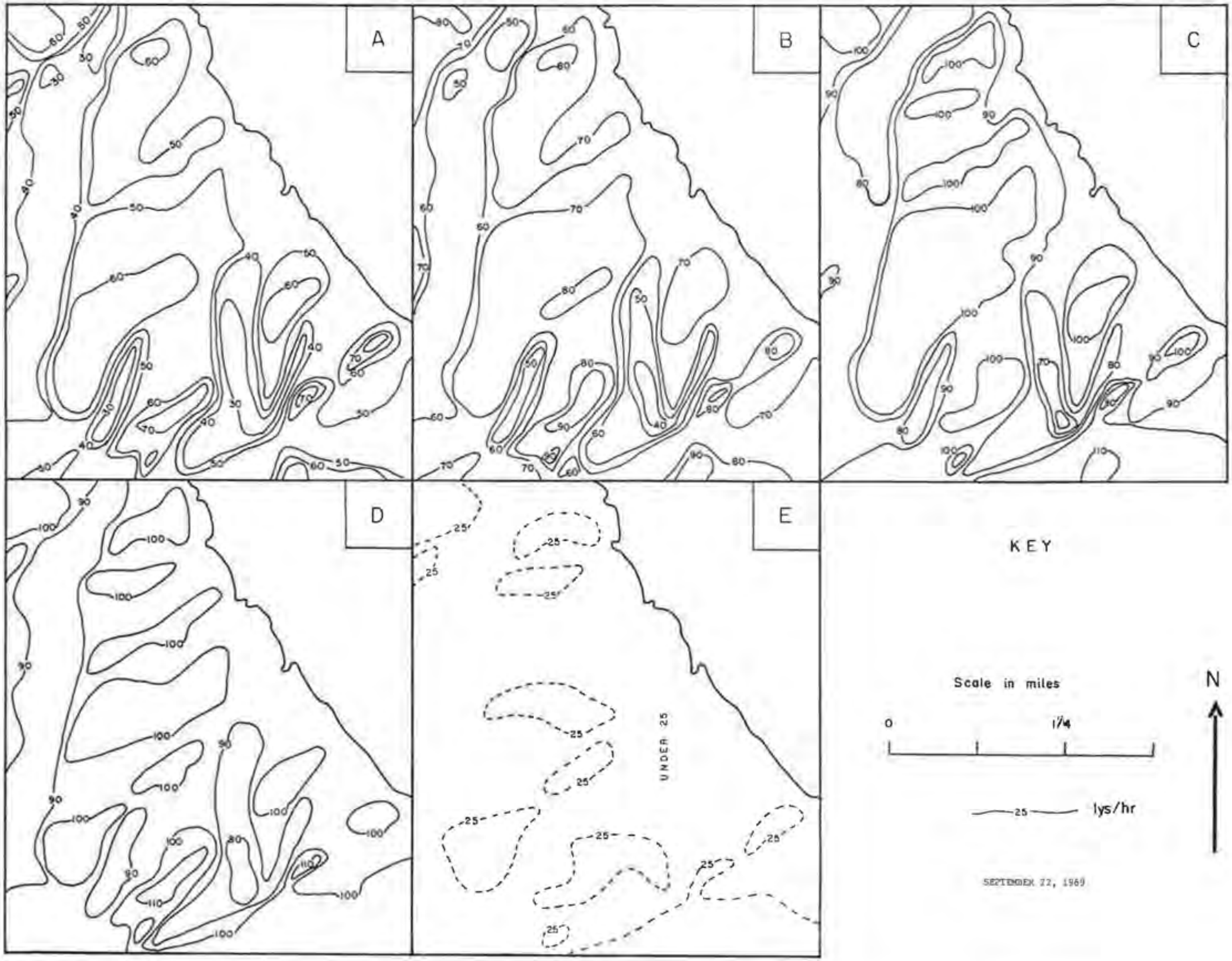

Fig. 4 Hourly Global Radiation, East Coast, Barbados, Sept. 22, 1969
A 0700-0800; B 0800-0900; C0900-1000; D 1000-1100; E1100-1200

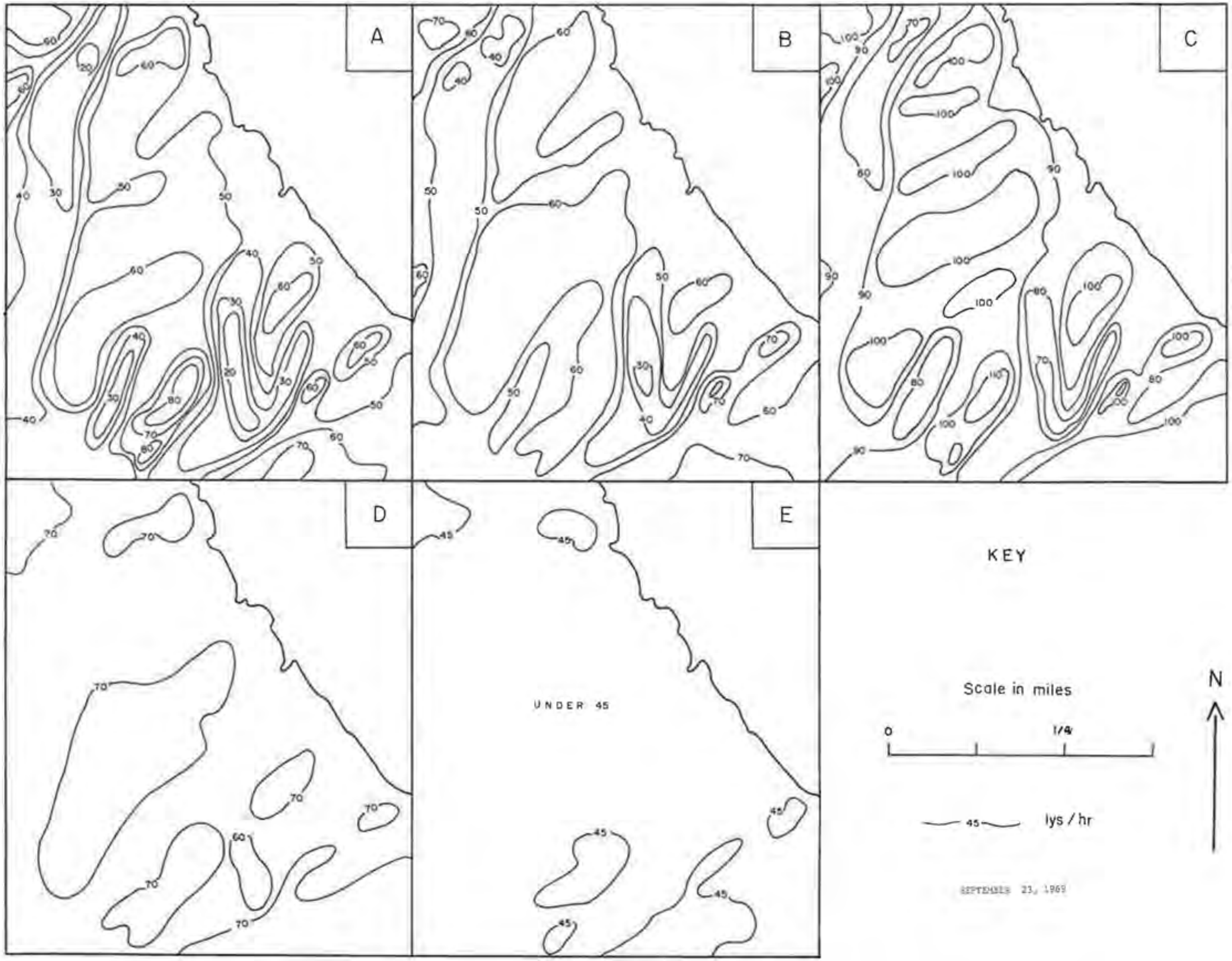

Fig. 5 Hourly Global Radiation, East Coast, Barbados, Sept. 23, 1969
A 0700-0800; B 0800-0900; C 0900-1000; D 1000-1100; E 1100-1200

An examination of the sequence of maps in Figs. 4 and 5 brings out the major importance of north/south trending ridge axes in providing boundaries for contrasting radiation areas. For example, the main crestline running north to south to the west of centre of the map provides the major break in the radiation distribution of the maps. The east to west physiographic trend is shown to be of secondary importance.

The radiation contrasts are greatest in the early morning when sun angles are low, but the total radiation received is still considerable. Between 0700-0800 the radiation over the map is about 50 ly. These contrasts persist until 1000 hrs. after which they disappear, so that there is very little contrast at noon. Similar contrasts, but on the opposite slope would be found in the late afternoon, but under the tropical convective weather regime, afternoons are more cloudy, with consequently less solar radiation received at the ground.

ACKNOWLEDGEMENT

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REFERENCES

Basnayake, B.K., 1968: "Two Maps of Direct Shortwave Radiation in Barbados", Climat.Bulln. (McGill Univ.), No. 4, pp. 21-30.

Fritchen, Leo J., 1967: "Net and Solar Radiation Relations on Irrigated Field Crops", Agr.Meteor., Vol. 4, pp. 55-62.

Garnier, B.J. & Ohmura, A., 1968: "A Method of Calculating the Shortwave Radiation Income of Slopes", Journ.Appl.Meteor., Vol. 7, pp. 796-800.

Garnier, B.J. & Ohmura, A., 1970: "The Evaluation of Surface Variations of Solar Radiation Income", Solar Energy, Vol. 13, pp. 21-34.

Garnett, Alice B., 1935: "Insolation, Topography and Settlement in the Alps", Geogr. Rev., Vol. 25, pp. 601-617.

Heywood, H., 1965: "The Computation of Solar Radiation Intensities, Part 2, Solar Radiation on Inclined Surfaces", Solar Energy, Vol. 10, pp. 46-52.

Kimball, H.H., 1922: "Daylight Illumination on Horizontal and Vertical Sloping Surfaces", Mo.Wea.Rev., Vol. 50, pp. 615-628.

Kondratyev, K.J. and Manolova, M.P., 1960: "The Radiation Balance of Slopes", Solar Energy, Vol. 4, pp. 14-19.

Monteith, J.L., and Szeicz, G., 1962: "Radiative Temperature in the Heat Balance of Natural Surfaces", Quart.Journ.Roy.Meteor.Soc., Vol. 88, pp. 496-507.

Ohmura, A., 1969: "Computation and Mapping the Shortwave Radiation on a Slope", M.Sc. Thesis, McGill University, Montreal.

Penman, H.I., 1948: "Natural Evaporation from Open Water, Bare Soil and Grass", Proc.Roy.Soc.Lond., (Ser.A), Vol. 193, pp. 120-145.

Shaw, R.H., 1956: "A Comparison of Solar Radiation and Net Radiation", Bull. Am. Meteorol. Soc., Vol. 37, pp. 205-209.

COMPARISON OF THE FIELD PERFORMANCE OF THREE TYPES OF SOLAR RADIATION MEASURING INSTRUMENTS

by

B. K. BASNAYAKE*

Despite considerable recent increases in the number of stations recording solar radiation, their total number remains small, and is far less than the number of stations recording temperature, rainfall and other climatic elements. One reason for this is that the extent of usefulness and reliability of the cheaper forms of radiation measuring instruments has not been thoroughly examined, and the tendency is, therefore, to accept only the results obtainable from the more sensitive and expensive instruments. For obvious reasons, the location of the latter is likely to be the sites of fully maintained climatological stations where trained personnel can operate them. To widen and expand the network of radiation observing stations, it is necessary to use simpler instruments. This can be done confidently only if their accuracy has been tested against more sophisticated sensing and recording systems so that their limitations and degree of reliability can be allowed for in using the results. The purpose of this article is to offer some instrument comparisons with this in view , using the results of test observations made recently in Barbados.

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The instruments tested were a Kipp and Zonen (Moll- Gorczynski) Solarimeter, a Belfort Bimetallic Actinograph, and a Gunn-Bellani Radiation Integrator. The three types of instrument vary in price, sensitivity, and ease of chart interpretation. The objective of the experiment was to test the cheaper and less sensitive instruments against the Kipp and Zonen system, test their performance under field conditions in a hot, humid environment, and arrive at some conclusions regarding their adequacy for micro and meso meteorological use.

A Kipp and Zonen (Moll-Gorczynski) Solarimeter is a thermopile-type radiation measuring instrument. Its sensitive surface consists of blackened alternate strips of manganin and constantan, with one set of junctions along the centre line of the surface. The remaining junctions are in good thermal contact with the relatively massive supporting posts which are insulated electrically but not thermally from the base plate. The receiving surface is covered with two concentric hemispherical glass domes, to shield it from wind and rain and to minimise convective currents within the instrument. When the instrument is set up, shortwave solar radiation penetrates the glass dome and heats the blackened surface, setting up an electromotive force which is measured by a galvanometer, and recorded by a suitable recording system (Meteorological Office, 1956).

The recording system used with the solarimeter in Barbados was a Rustrak Model 157 amplifier-recording system with adjustable sensitivity. Its range of sensitivity of from 1 to 100 millivolts full scale could easily accommodate the solarimeter output of 6-8 mv ly^{-1}. The recording was done on pressure sensitive paper, by means of a chopper striking the galvanometer stylus, the chopper speed being adjusted to chart speed.

In the model used, the chart speed of 1 inch per hour was matched with a chopper speed of one strike every 2 seconds. This gave a nearly smooth line on the chart at most times, except when the passage of clouds produced rapid variations in the amount of solar radiation received.

The excellent sensitivity and versatility of the Kipp/Rustrak system was very evident in the investigation. Variations in shortwave radiation were sensed and indicated within a few seconds. With a chart speed of 1 inch per hour, the recording allowed for five-minute averages to be read off with ease. As the solarimeter itself was separate from the recorder, it could be easily mounted in almost any locality. It required only a light support, and the wires leading to the recorder could easily be concealed. It is important to keep supporting bulk to a minimum in order to reduce artificial reflecting surfaces to a minimum. The fact that the sensor could be mounted in any position meant that it could be used in an inverted position for albedo measurements, and mounted at an angle to the horizontal for measuring radiation on slopes. The small size of its sensitive surface allowed the use of a comparatively narrow shade ring in sky-diffuse radiation measurements, so that interference by the shade ring was minimal.

One disadvantage of the system, which initially caused some trouble, was the sensitivity of the Rustrak recorder to high humidity. This was overcome by keeping the recorder enclosed in a plastic bag in field use. When the instrument was badly affected by humidity it could be restored to proper functioning by 'baking' overnight in an incubator.

In the Belfort Bimetallic Actinograph, the receiving surface consists of two rectangular bimetallic strips, one coated black and exposed and the other covered by a highly polished radiation shield. Because of the different rates at which the two surfaces absorb radiation, their temperatures, and consequently, their movements, differ. The movements are sensed by a lever mechanism connected to a pen, and are recorded on a chart attached on a clock-driven drum.

The Belfort Bimetallic Actinograph, equipped with a daily clock, provided satisfactory five-minute averages of shortwave global radiation, and, when equipped with a shade ring, sky-diffuse values. The advantages of the instrument are its robust construction, its cheapness, its effectiveness in providing short-period values, its not requiring electricity, and its being unaffected by high humidity. However, it is less sensitive than the Kipp/Rustrak system, is somewhat bulkier because the sensor and recorder cannot be mounted separately, and does not operate at an angle to the horizontal. The last characteristic was not a serious disadvantage in investigating topographic variations of global radiation, because, with the global and sky-diffuse values on the horizontal, the corresponding values on any slope can easily be calculated. (Garnier & Ohmura, 1968, 1970).

The Gunn-Bellani Radiation Integrator contains a globe-shaped radiation absorbing surface made of thin copper plate, blackened on the outside. When exposed to sunlight the heat absorbed by the black sphere is used to distil water or alcohol contained within the black bulb, the amount of distillate being proportional to the incident solar radiation. Therefore the distillate is read periodically and recorded.

Pereira (1959), Davies (1965), McCulloch and Wangati (1967) all attest to its usefulness in the Tropics.

The Gunn-Bellani Instrument was the cheapest instrument of the three tested. It is easily installed, and needs very little maintenance. Its comparatively high 'radiation threshold' below which distillation is negligible (about 160 ly day $^{-1}$ according to Pereira (1959)) was no serious handicap for obtaining daily totals of incident solar radiation in the tropics because this value was exceeded on most days. It was, however the least sensitive of the three instruments tested.

Tests of global radiation measurement with the three instruments were carried out in Barbados at two sites and the results analysed by correlation using the method of least squares (Table One). The observations at Cottage in this table were made during a six-day period in July 1969, whereas the Waterford observations comprised measurements at different times in July, August, September and December of the same year.

TABLE ONE

Type	No.	Site	Correlation
Hourly Global (KR v. B)	71	Cottage	0.98
Hourly Diffuse (KR v. B)	64	Cottage	0.93
Daily Global (KR v. B)	36	Waterford	0.92
Daily Global (KR v. G)	33	Waterford	0.82

KR = Kipp/Rustrak system ; B = Bimetallic Actinograph; G = Gunn-Bellani Radiation Integrator.

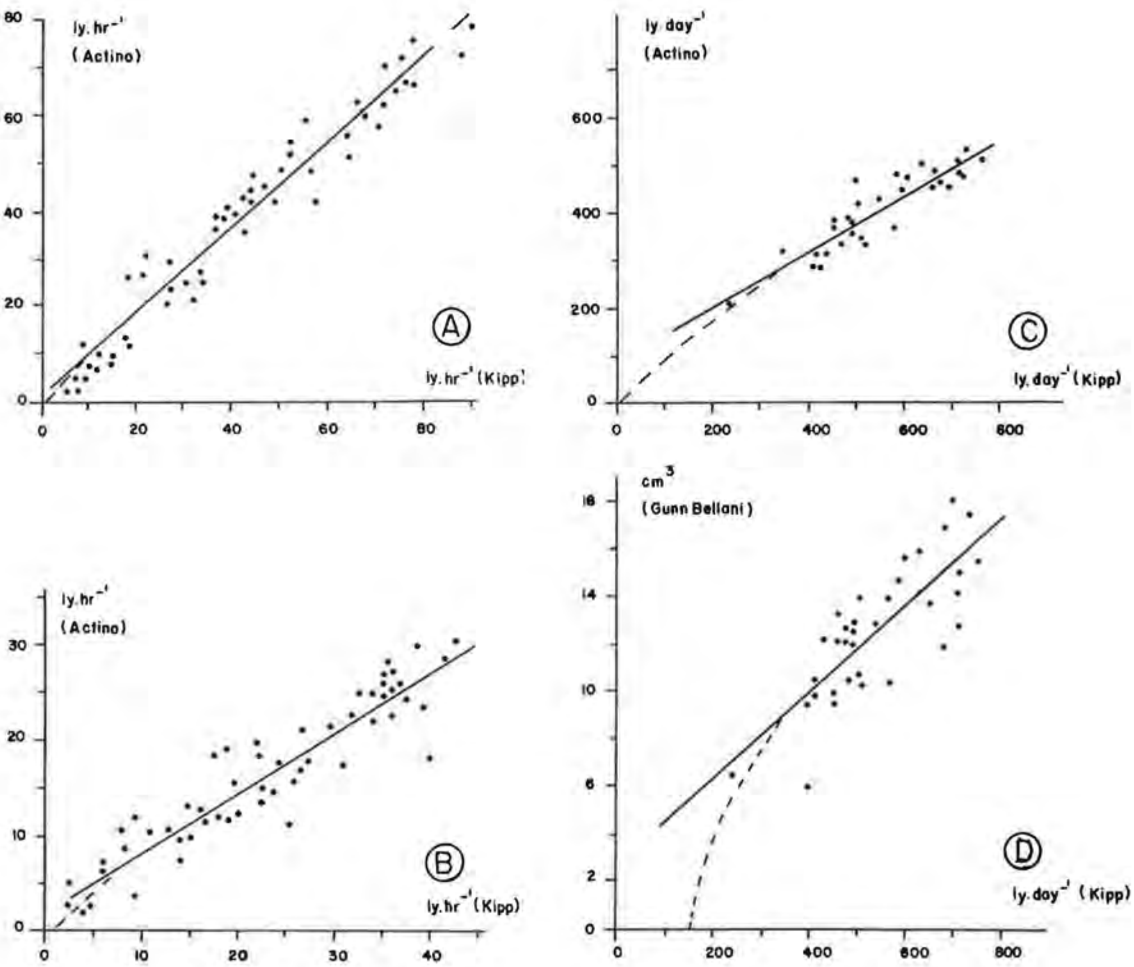

Fig. 1 Scatter Diagrams of Instrument Comparisons

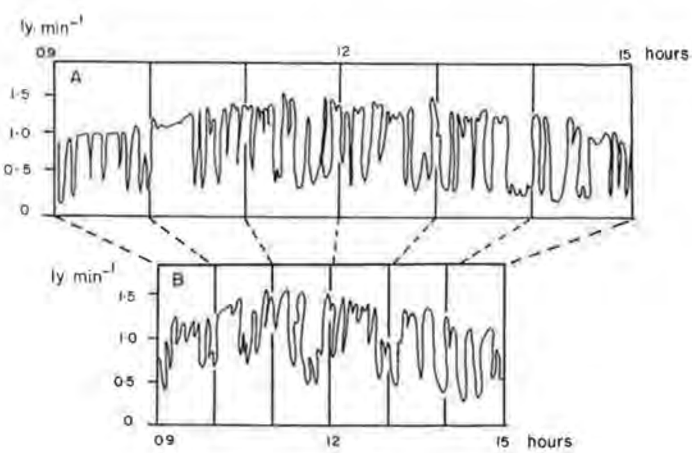

Fig. 2 Sample Recorder Traces; upper - Kipp;
lower - Actinograph

Scatter diagrams illustrating the different comparisons are given in Fig. 1. The figures comparing global radiation measurements using the Kipp/Rustrak system and the Belfort Actinograph clearly show the latter's lower sensitivity (figs. 1(a), (b), (c)). The lower values recorded by the actinograph are largely due to its relatively large time lag coefficient about 5 to 10 minutes, as opposed to a few seconds for the solarimeter. The effect is particularly great during days with rapid alterations between clear sun and cloud-covered sun periods which are typical of the rapidly moving cumulus of the Trade Wind Belt. The effect is clear in an examination of the respective recorder charts, a sample of which is given in Fig. 2. The lag in the 'peaks' of the actinograph chart is partly compensated for by a similar lag in the 'lows', but the net effect remains a loss. The scatter of points in Fig. 1 (a) may, therefore, be attributed partly to the different lag coefficients of the two instruments and partly to different rates of alternation between clear and cloud-covered sun at different hours. The lower sensitivity of the actinograph in recording sky-diffuse radiation (fig. 1 (b)) is partly due to the wider shade ring used ($5\frac{1}{2}$" wide as compared with $2\frac{1}{2}$" of the solarimeter) because of the actinograph's larger sensitive surface. Consequently, the wider scatter of points in Fig. 1 (b), than in Fig. 1 (a) while being due partly to the differing instrumental lag, also contains the effect of the different shade rings used. The lower degree of correlation of the daily totals ($r = 0.92$) as compared with that of the hourly totals ($r = 0.98$) is probably mainly a weather effect. The hourly values were obtained by measurement on five consecutive days, when the weather was probably relatively homogeneous, while the daily totals were from selected days over four different months. The slope of the regression line in Fig. 1 (c) is probably not reliable enough for calibration of the actinograph, there being so few sufficient points near the origin. The regression given in Fig. 1 (a), therefore is more suitable for this purpose.

The correlation of the Gunn-Bellani Radiation Integrator against the Kipp solarimeter (fig. 1 (d)) shows a fairly high reliability in spite of the integrator's high 'threshold value' and the differing geometry of its sensitive surface as compared with that of the solarimeter. The regression line of the graph is, however, somewhat suspect because of the insufficiency of points near the origin.

In general, it may be concluded that the Belfort Bimetallic Actinograph, provided it is calibrated beforehand against a more sensitive instrument such as a Kipp solarimeter, is a good instrument for field actinometric measurements, and performs well in a humid tropical climate. The Gunn-Bellani Radiation Integrator is an even still cheaper actinometric field instrument which is useful in the tropics to give daily totals. However, no chart recording to give diurnal distribution is possible in this case. Consequently, where such distribution is desirable and where sky-diffuse radiation is also requested, the bimentallic actinograph appears as probably the most economically useful instrument for general purposes.

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REFERENCES

Davies, J.A., 1965: "The Use of a Gunn Bellani Distillator to Determine Net Radiation Flux in West Africa", Journ.Appl.Meteor., Vol. 4, pp. 547-549.

Garnier, B.J. & Ohmura, A., 1968: "A Method for Calculating Shortwave Radiation Income of a Slope", Journ.Appl.Meteor., Vol. 9, pp. 796-800.

Garnier, B.J., & Ohmura, A., 1970: "The Evaluation of Surface Variations in Solar Radiation Income", Solar Energy, Vol. 13, pp. 21-34.

Meteorological Office, 1956: "Handbook of Meteorological Instruments", HMSO, London.

McCulloch, J.S.G., & Wangati, F.J., 1967: "Notes on the use of a Gunn Bellani Radiometer", Agr.Meteor., Vol. 4, pp. 63-67.

Monteith, J.L., Szeicz, G. 1960: "The Performance of a Gunn Bellani Radiation Integrator", Quart.Journ.Roy.Met.Soc., Vol. 86, pp. 91-94.

Pereira, H.C., 1959: "Practical Field Instruments for Estimation of Radiation and of Evaporation", Quart.Journ.Roy.Met.Soc., Vol. 85, pp. 253-261.

THE CLIMATE OF MONT ST.HILAIRE

A personal impression

by

P. D. Baird*

For almost ten years I maintained a record of temperature and precipitation at Gault House, Mont St. Hilaire. Observations were made twice daily (8 a.m. and 6 p.m.) usually by myself, but when absent by my wife or a substitute director.

Maximum, minimum, and actual temperatures were recorded in a standard Stevenson screen; rainfall in a standard meteorological gauge; snowfall by various, often somewhat subjective, measurements. Monthly and weekly records were forwarded to Quebec and a monthly abstract also distributed to, among others, McGill Observatory.

The station site close to the Gault House is not ideal, the rain gauge being a bit more overshadowed by trees than officially allowable, and the area subject to drifting snow. Hence measurements of snow were often taken 200 to 300 yards downroad in the bush.

During the last two of the 120 months of recorded information, after I had left Gault House, the temporary substitute observer failed to observe precipitation accurately. Hence precipitation figures for November and December 1969 in this report are copied from the neighbouring station at Rougemont, some eight miles distant.

The ten-year record is, I think, sufficiently lengthy and well

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documented to show important trends in the local climate at 570 feet above sea level and can form a basis for scientific observations in the general area. For future research it is unfortunate that the records are not being maintained.

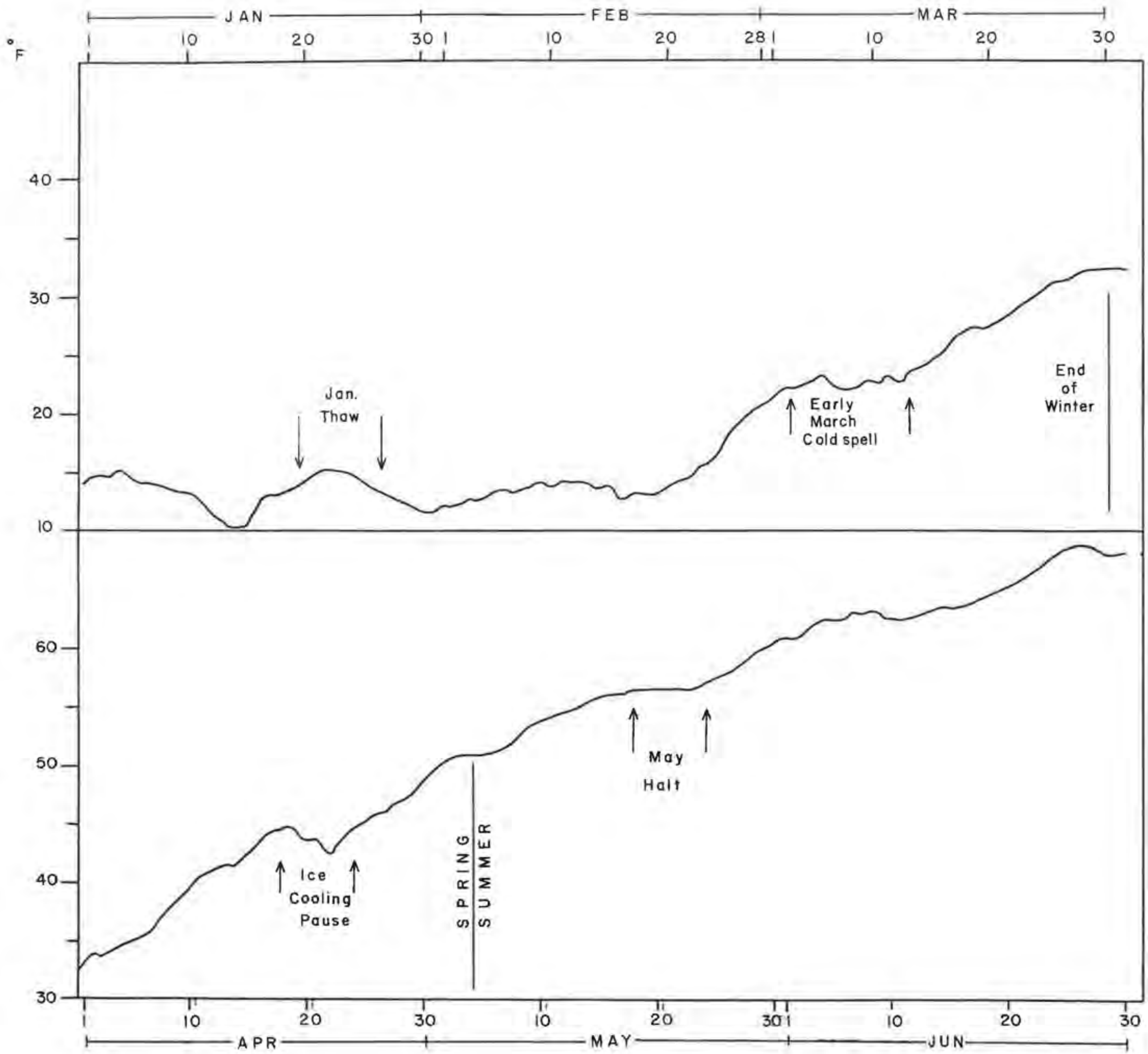
THE TEMPERATURE REGIME

Medieval folk began their year on 25 March or thereabouts. I believe they were right. However modern practice starts the year on 1 January and hence this paper will reluctantly treat results this way.

I have analysed the ten year records of temperature (mean daily) into a ten-day running mean (after experimenting with a 5-day running mean which seemed unsatisfactory). Graphs of this parameter are shown in fig. 1 and the remarks below are based on these, with interpolations of extraordinary situations.

Considering the classic division of the climate into Spring, Summer, Fall and Winter, and acknowledging these divisions to relate to mean temperatures of less than 32°F or 0°C as Winter, between 32°F and 50°F (0° and 10°C) as spring and fall, and above 50°F (10°C) as summer, we obtain for Mont St. HIlaire the following division of the year into seasons:

	Rough approx.	Closer	More accurate
Spring	10%	5 weeks	38 days (28 March - 4 May)
Summer	40%	22 weeks	155 days (5 May - 6 Oct.)
Autumn (Fall)	10%	6 weeks	41 days (7 Oct.-16 Nov.)
Winter	40%	19 weeks	131 days (17 Nov.- 27 March)


JAN
FEB
MAR
°F
40
30
20
10
Jan. Thaw
Early March Cold spell
End of Winter
60
50
40
30
Ice Cooling Pause
SPRING
SUMMER
May Halt
APR
MAY
JUN

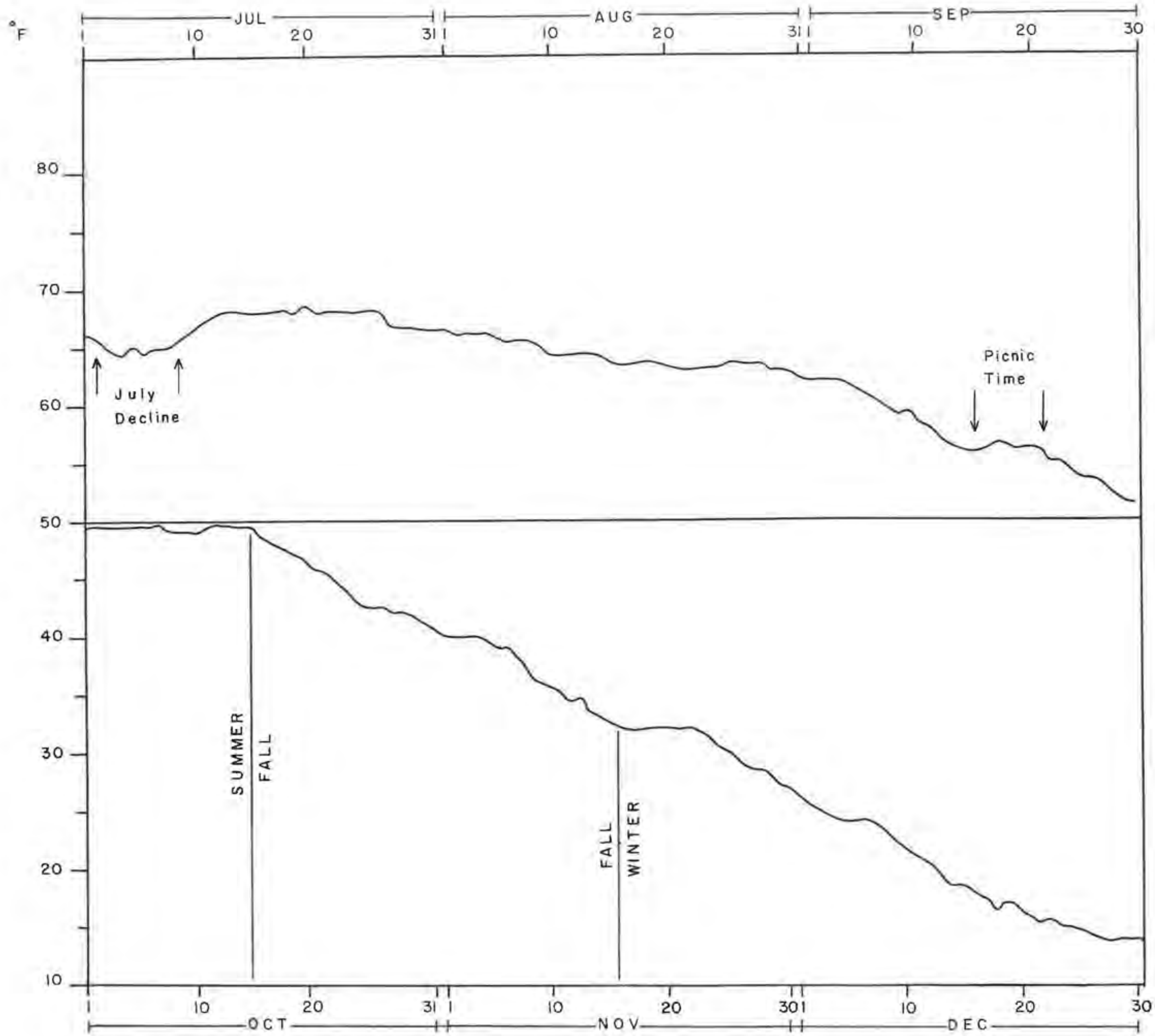


Fig. 1 Ten-day Running means of temperature, Mont St. Hilaire

(a) Winter: The graph shows that the New Year begins with a pause in temperature decline. This is often accompanied by heavy snowfall. But then occurs the deepest dip of winter centred on the 14th to 16th of January. Another cold spell runs through the end of the month and into February but between them comes the infamous January thaw period which shows up strongly on this ten year record (and even on the McGill Observatory's story of nearly ten times as long). From the 19th to the 26th January each day has a 40% chance of rising above freezing, whereas never in the ten years did this happen on the 16th, 27th or 28th. The coldest day in the ten years was 8 January 1968 when the mean temperature was -21°F.

Winter however is far from over in February. Although this month sees a fractionally higher mean temperature than January, it sees no more days (14 in ten years) when the mean temperature is above freezing, and has, indeed, recorded the lowest minima (-28°F) on 2 February, 1962 and 13 February 1967, whereas January's lowest minimum was -25°F.

During most of February the temperature is more stable than in January. But about the 19th a steady climb starts which continues to the month's end; and this is strong as the sun heads north. There is a short "warm spell" around the 10th-12th. Nevertheless there tends to be less than six days in an average February when we have a shade thaw as opposed to $7\frac{1}{2}$ days in January.

The powerful rise which started the temperature climb on 19 February continues into March. But then a cold spell intervenes from about the seventh to the twelfth. Thence, until the twenty-eighth we have another steady rise and as March ends and April begins another cool spell - "the lion of March" - takes place. March has no day with a mean subzero temperature, but minima below 0°F occur on about two March nights each year and the 17th and 18th of the month are susceptible to this. Poor St. Patrick!; not only thrown out by an unsympathetic pope, but thrown into the cold to boot.

(b) Spring: By the twenty-eighth of March the average temperature has climbed to 32°F and now spring begins. Nine March days have a mean temperature above freezing mostly, of course, toward the end of the month, but the years 1964, 1965 and 1966 all had five or six of these days in the first week.

The temperature rises steadily through most of April but there is a pause between the 18th and 24th. This could be a local phenomenon. The average date for the last snow cover on the ground is 15 April but for last ice on the lake it is the 23rd, and the proximity of the weather station to this large area of melting ice could be responsible for the damper on a temperature rise. The average date of last air frost is 4 May, average daily temperature should have climbed above 50°F and we are into summer.

(c) Summer: But not necessarily into the planting season. In 1969 the mean temperature only staggered above 50°F on 15 May - ten days late and that without an actual May air frost. One can expect one of these per year but frost occurred as late as 31 May in 1961 and there were seven frosty nights in May 1966, including one day when the daily mean was below freezing.

The first week (5-12 May) yields a pause in temperature rise. Thereafter it climbs fast until the 17th tempting the gardener to put in annuals. But wait! The next week shows a drop and it is not until the 24th that the thermometer starts climbing again. This is, rightly, the traditional planting day. Vive la reine Victoria!

The 9-16 June is a cool week, then there is a midsummer surge carrying through to the 27th. There follows a noticeable decline of more than 3°F but by 12 July we catch up again and declare High Summer for two weeks. It is however during the ten-year mean decline that the absolute maxima have been recorded: 90.8°F on 30 June 1964 and 90.3°F on 2 July 1963 - the only two >90°F recordings. A mean of 69.9°F is the ten-year average for our warmest day, 18 July.

Most of August, shows a gentle decline of temperature but with a brief pause toward the end; in September the fall is steeper, broken by a 'little summer' 15th to 22nd - ideal picnic time.

(d) Fall: From 1 to 15 October the ten-year mean, hovering around 50°F, falls only 1°F (with a greater dip, however, around the 9th). This, I suppose, is "Indian Summer", though the mean date of first air frost is not till the 15th October. But this is very variable: it has occurred as early as 28 September and as late as 3 November. Once this Indian summer is over the Fall is really on and temperature drops at its greatest rate, 7°F in 10 days, and continues so to do until 17 November when it dips below the freeze point marking the beginning, at first hesitant, of real winter.

(e) Winter Again: After November 25th the temperature declines sharply until three days after Christmas. Then begins the warmer (but often strong) spell ushering in the New Year and its first extraordinary week.

Table One shows the monthly average temperatures for the ten-year period. When compared with observations taken at the McGill Observatory, these have shown a remarkably constant average difference from the McGill campus averages, varying from 2.5°F to 3.5°F lower with an average of 3°F difference. One of these degrees could be attributed reasonably to elevation difference (570 feet of Mont St. Hilaire versus 180 at McGill) the other two to "City stifling".

PRECIPITATION

The area around Montreal is blessed with a rather stable precipitation regime, well spread month by month, and giving reasonably slight variation from year to year, the annual variation being within 15% of the mean. Nevertheless, individual months can show great variations and no such day by day graph as was produced for temperature would be significant.

The monthly totals of precipitation are shown in Table Two for the ten years of observation and the ten-year averages of precipitation elements are given in Table Three. In both these tables, ten inches of snow is considered as equivalent to one inch of rain, and this conversion value is used to calculate total precipitation.

TABLE ONE

MEAN MONTHLY TEMPERATURES - GAULT HOUSE MONT ST. HILAIRE

°F

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	10 years Average
Jan.	12.7	7.5	11.5	13.8	20.0	11.3	13.3	20.3(w)	7.4(c)	16.6	13.4
Feb.	20.5(w)	18.1	10.9	7.7(c)	16.1	14.1	16.3	7.7(c)	10.2	19.2	14.1
Mar.	22.1	25.1	29.9	25.5	27.7	26.2	28.8	21.9(c)	30.2(w)	24.9	26.2
Apr.	40.7	39.4	39.0	40.6	40.0	39.5	39.8	38.9	46.0(w)	38.3(c)	40.2
May	59.6(w)	51.7	55.8	52.4	57.2	55.8	50.7	47.5(c)	53.0	50.7	53.4
June	63.6	61.7	64.2	64.6	63.1	62.9	63.9	65.9(w)	60.1(c)	62.5	63.2
July	65.8	67.4	63.6	68.6(w)	68.6(w)	63.2(c)	67.9	67.9	67.6	67.2	66.8
Aug.	65.9	66.0	65.3	61.5(c)	61.5(c)	63.4	65.2	64.7	62.3	67.8(w)	64.4
Sept.	58.2	63.9(w)	55.1	53.1(c)	55.5	57.6	54.6	57.5	60.8	56.2	57.3
Oct.	45.6	49.4	45.1	52.6(w)	44.9	44.4(c)	46.4	46.5	50.4	45.5	47.1
Nov.	38.0	36.4	31.3	38.4	33.9	30.4(c)	38.6(w)	30.9	31.0	35.4	34.9
Dec.	17.0	22.3	17.4	10.0(c)	20.7	23.3(w)	20.9	22.6	15.7	19.2	19.0
Year	42.5	42.5	40.7	40.7	42.4	41.0	42.2	41.0	41.1	42.0	41.7(42°)

w = warmest month

c = coldest month

TABLE TWO

TOTAL PRECIPITATION IN INCHES
GAULT HOUSE MONT ST. HILAIRE

(figures in inches)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	10 Year Average
Jan.	2.90	1.58 (d)	2.99	2.05	4.47 (w)	3.06	3.93	2.65	2.21	3.50	2.93
Feb.	5.19 (w)	2.60	3.22	3.10	1.72	2.96	2.91	2.42	2.44	1.61 (d)	2.82
Mar.	3.46	3.31	2.04	3.18	2.87	0.86	2.85	0.73 (d)	4.14 (w)	2.78	2.62
Apr.	3.10	5.33 (w)	4.37	4.05	2.21	2.25	0.93 (d)	2.67	2.69	2.87	3.05
May	3.32	2.67	2.08	3.80 (w)	2.22	2.53	2.06	2.70	1.90 (d)	2.99	2.63
June	3.41	3.84	3.25	2.16	1.21	1.10 (d)	4.18	4.14	3.59	5.63 (w)	3.25
July	4.23	3.78	5.69 (w)	3.23	4.01	4.93	2.36 (d)	4.14	4.72	2.47	3.96
Aug.	2.30	6.54	3.39	7.93 (w)	4.54	7.09	3.25	3.32	2.10 (d)	3.58	4.40
Sept.	4.57	0.88 (d)	2.49	4.82 (w)	1.36	4.49	3.08	2.18	2.00	2.91	2.88
Oct.	4.30	3.65	4.94 (w)	0.52 (d)	2.36	4.78	1.87	3.92	3.04	2.51	3.19
Nov.	3.21	2.43	1.47 (d)	6.31 (w)	3.03	4.65	4.04	2.97	5.41	6.00	3.95
Dec.	2.53	3.92	3.64	1.77 (d)	3.43	2.49	5.42 (w)	3.67	4.22	3.93	3.50
Year	42.52	40.53	39.57	42.92	33.43	41.19	36.88	35.51	38.46	40.78	39.18

(d) = driest month

(w) = wettest month

TABLE THREE

TEN-YEAR AVERAGES OF PRECIPITATION ELEMENTS

	Rain	Snow	Total Precipitation (figures in inches)	Snow depth 1st of month	Snowfall Last in Spring	Snowfall First in Fall	Thunder Days
Jan.	0.87	20.6	2.93	14			-
Feb.	0.66	21.6	2.82	21			-
Mar.	1.08	15.4	2.62	26			-
Apr.	2.46	5.9	3.05	15	25th		1
May	2.43	2.0	2.63	-			3
June	3.25	-	3.25	-			6
July	3.96	-	3.96	-			8
Aug.	4.40	-	4.40	-			5
Sept.	2.88	-	2.88	-			2
Oct.	3.05	1.4	3.19	-		29th	1
Nov.	2.87	10.8	3.95	-			-
Dec.	1.02	24.8	3.50	3			-
Year	28.93	102.5	39.18				26

(a) Rainfall: Rainfall can be quite variable particularly during summer thunderstorms, the narrow paths of which can hit or miss in specific localities. Moreover, the moist air masses of winter can sometimes change snow to rain. Nevertheless rain is rare in the winter months and has been nil in February 1963, 1964, 1967 and 1969, and in March 1965.

The most disastrous freezing rain (over one inch) fell in late February 1961. Another, as damaging to trees, occurred in 1968, on November 28-29. No 'climate day' (8 a.m. to next 8 a.m.) has recorded over two inches of precipitation but several have come close, and a given

24 hours could have exceeded it. An average 167 days in the year have measurable precipitation but this varies from $10\frac{1}{2}$ days (ten Septembers) to 21 days (ten Decembers) and from 5 days (October 1963 and March 1965) to 25 days (December 1964).

(b) Snowfall: Fig. 2 portrays the monthly snowfall for each of the ten winters. It will be seen that on two years snow fell in May, on two years there was none after the end of March, on three years there was snow in October.

The months with the greatest snowfall have been: Feb. 1960, 43.4 inches; Dec. 1968, 40.7; Jan. 1966, 38.4; Dec. 1962, 34.6; Feb. 1963, 31.0.

Some other snow data are shown in Table Four. In this table 'first skiing' means the date when snow cover exceeds 12 inches, 'last skiing' when this falls below 16 inches (at which time bare patches and melt.water will be apparent). The mean duration of snow cover is 135 days, of the skiing season 82 days, and maximum depth of snow cover averages 31 inches on the 2nd of March.

A final word is needed on the status of ice on Lac Hertel. This lake is frozen for the best part of five months per year. The date of ice initiation is difficult to determine. Ice comes and goes at first but usually comes to stay in the first week in December. The date of last ice, however, has been catalogued each year and averages 23 April, varying between rather narrow limits, the earliest date being 13 April (1969) and the latest 1 May (1961).

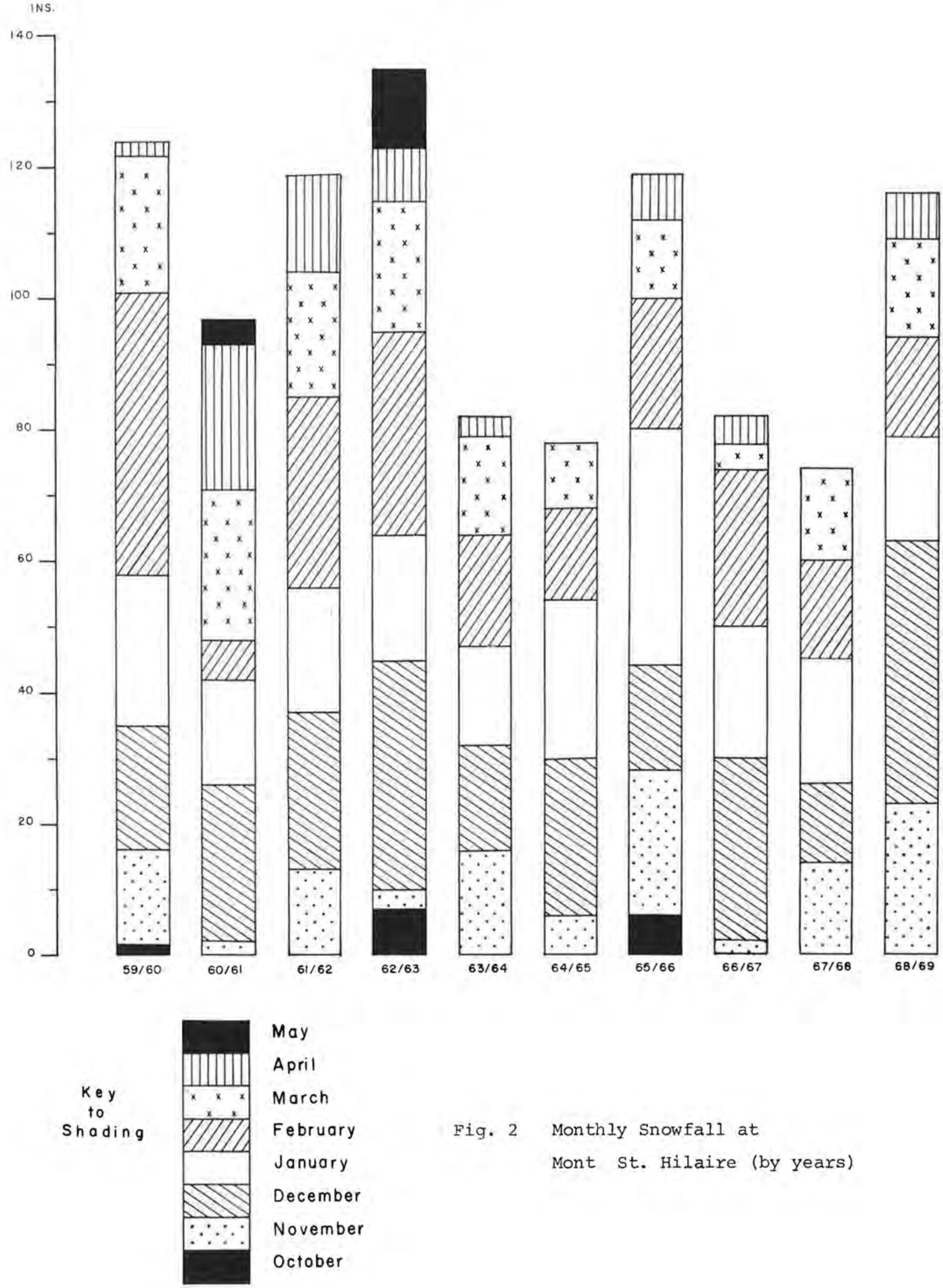


Fig. 2 Monthly Snowfall at Mont St. Hilaire (by years)

TABLE FOUR

SOME SNOW DATA 1959-1969 GAULT HOUSE, MONT ST. HILAIRE

Year	Snow Cover First	Snow Cover Last	Days Duration	Adequate for skiing First	Adequate for skiing Last	Adequate for skiing Days Duration	Maximum depth inches	Date of Maximum Depth
1959/60	7 Dec.	12 Apr.	128	-	-	-	-	-
60/61	8 Dec.	22 Apr.	134	1 Jan.	6 Apr.	95	33	15 Mar.
61/62	27 Nov.	19 Apr.	143	29 Dec.	5 Apr.	97	39	15 Mar.
62/63	7 Dec.	17 Apr.	132	23 Dec.	5 Apr.	103	44	6 Mar.
63/64	9 Dec.	13 Apr.	125	1 Jan.	5 Mar.	64	19	22 Feb.
64/65	4 Dec.	8 Apr.	125	26 Jan.	6 Mar.	39	20	6 Feb.
65/66	17 Nov.	17 Apr.	151	22 Jan.	3 Apr.	71	34	26 Feb.
66/67	19 Dec.	13 Apr.	115	29 Dec.	2 Apr.	93	35	2 Mar.
67/68	12 Nov.	1 Apr.	139	15 Jan.	21 Mar.	65	22	12 Mar.
68/69	8 Nov.	20 Apr.	163	4 Dec.	13 Apr.	130	36	28 Feb.
10 Year mean	30 Nov.	14 Apr.	135	31 Dec.	25 Mar.	84	31	2 Mar.

IMPORTANCE OF DAILY AND SYNOPTIC CLIMATIC ANALYSES IN ECOLOGICAL STUDIES: AN EXAMPLE FROM NIGERIA

by

Kala Swami*

The presence or absence of moisture to a greater or lesser degree is widely recognised as being a major factor in the study of natural regions and their ability to support a particular type of vegetative cover. Within the field of plant ecology, this aspect of an area's climatology tends to be examined mainly in terms of mean annual or mean monthly values (Aubréville, 1949), although some consideration has been given to the frequency of occurrence of different monthly values, as in Russell's treatment of the idea of climatic years (Russell, 1934). In studying moisture in this way two specific aspects are generally considered: firstly, the arrival of moisture as precipitation in terms of quantity and seasonal distribution, and secondly, the amount of evaporation that occurs, and the resulting water balance situation.

These methods of analysing monthly precipitation have been applied by several authors to studies of moisture characteristics as a differentiating factor between vegetation zones. This is particularly true of tropical studies. Thornthwaite's 1931 classification of climates (Thornthwaite, 1931), for example, stressed the importance of moisture

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as a basis for vegetation contrasts where temperatures are non-limiting for plant growth. It is not surprising, therefore, that work on tropical vegetation, particularly on the savanna and forest ecosystems, has laid stress on the importance of precipitation and seasonal moisture conditions (Eyre, 1963, Dansereau, 1957, Tansley, 1935).

The principal differences in the climatic environment of these two major tropical vegetation ecosystems have thereby been found to be expressed in the duration of the rainy season rather than in contrasts in the character of the wet season in itself (Aubréville 1949, Beard, 1944). In general it would seem that the conclusion reached is that the savanna experiences a seasonal contrast between a reliably "wet" and a reliably "dry" season, and that this makes the moisture conditions of the savanna appear to resemble the forest conditions in the wet season and those of the desert in the dry season.

Considering conditions in annual or monthly terms however, masks the fact that the climate of an area is, in actuality, a generalised expression of situations that occur in short time units, which can be examined on a daily basis and which, if broken up into still smaller units, comprise hourly conditions as well. Hence the examination of moisture as an ecological element should at least consider the possibility of using the daily situation as a basis of study since the day to day characteristics in fact produce the totality of the climatic processes. The purpose of the present article is to explore this point of view further by investigating, on a daily basis, moisture conditions in the forest and savanna regions of Nigeria.

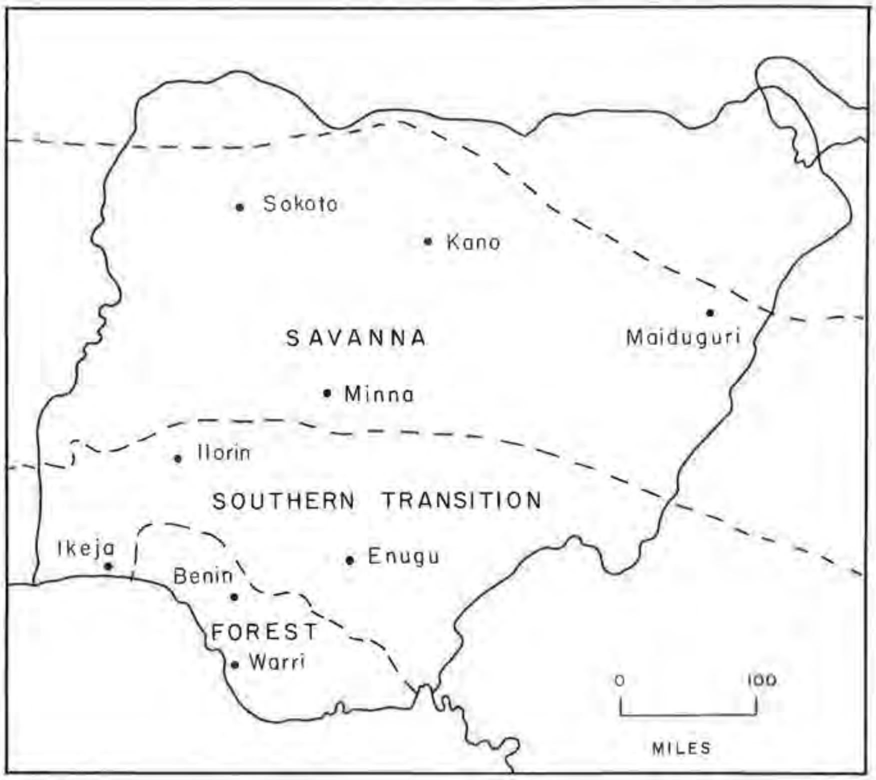

Fig. 1 Location of Stations and Vegetation Regions

TABLE ONE

DAILY PRECIPITATION CHARACTERISTICS

	BENIN					ENUGU					ILORIN					KANO					SOKOTO				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
June																									
25mm.+	161	4	40	55	22	111	3	37	46	17	138	3	46	63	16	29	1	29	28	9	47	1	47	55	8
12-25mm.	87	5	17	30	28	72	4	18	30	22	52	4	13	23	21	31	2	15	30	18	23	1	23	27	8
less 12mm.	47	9	5	15	50	56	11	5	24	61	30	12	3	14	63	43	8	5	42	73	15	5	3	18	84
Total	295	18	16	100	100	239	18	13	100	100	220	19	12	100	100	103	11	9	100	100	85	7	12	100	100
July																									
25mm.+	283	5	57	69	25	142	3	47	56	17	113	3	38	67	23	123	3	41	50	18	115	3	38	58	21
12-25mm.	54	3	18	13	14	64	4	16	25	22	47	3	18	28	23	83	4	21	34	23	53	3	18	27	21
less 12mm.	73	14	5	18	61	48	11	4	19	61	9	7	1	5	54	38	10	4	16	59	30	8	4	15	58
Total	410	22	19	100	100	254	18	14	100	100	169	13	13	100	100	244	17	14	100	100	198	14	14	100	100
August																									
25mm.+	114	3	38	60	20	77	2	39	60	16	29	1	29	28	11	186	5	37	54	28	119	3	40	52	23
12-25mm.	47	3	16	25	20	20	1	20	15	8	55	3	18	52	33	89	5	18	26	28	65	3	22	28	23
less 12mm.	28	9	3	15	60	32	9	3	25	76	21	5	4	20	56	68	8	9	20	44	45	13	3	20	54
Total	189	15	13	100	100	129	12	11	100	100	105	9	12	100	100	343	18	19	100	100	229	19	12	100	100
Sept.																									
25mm.+	227	5	45	58	23	162	4	41	60	17	154	3	51	56	16	67	2	33	52	15	51	1	51	41	10
12-25mm.	92	5	18	24	23	53	3	18	20	13	74	4	19	27	21	28	2	14	22	15	47	3	16	38	30
less 12mm.	71	12	7	18	54	53	16	3	20	70	47	12	4	15	63	34	9	4	26	70	25	6	4	21	60
Total	390	22	18	100	100	268	23	12	100	100	275	19	14	100	100	129	13	10	100	100	123	10	12	100	100

Key to Columns: (1) Total Rainfall in mm. (2) Number of days of Rain (3) Mean Rain per Rainy Day (4) % of Total Rainfall (5) % of Total Rainy Days

In general climatological data at the daily level of detail are not easily available and in the present case it has been necessary to examine conditions over a relatively short period of time determined by the availability of statistics. Both published and unpublished data from the Nigerian Meteorological Service have been used. Precipitation records covering a period of five years formed the chief basis of the analyses. In addition, records of hours of bright sunshine for a period of four years were obtained and records of temperature, vapour pressure, and wind were available for a period of two years. A combination of all these data enabled the calculation of water balance to be undertaken. Fig. 1 is a map of Nigeria showing the location of stations used for the analyses presented here, and in the different vegetation regions.*

Attention has been focused on the four rainy months of June, July, August and September and as a basis for study the days have been classified into: days with more than 25 mm of rain, days with 12 mm to 25 mm of rain, days with rainfall less than 12 mm, and days without rain. Some attention was also paid to days with a trace of rain. It was found, however, that this classification made little contribution to the features of the differentiating elements and consequently such days were classed as days without rain. Table One presents an analysis of these categories from the viewpoint of the amount of rain each one brought and the corresponding frequency of rain days.

The table suggests a general similarity between the wet season

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* A fuller account of how the different vegetation regions were determined may be found in Swami, 1970.

TABLE TWO

ATMOSPHERIC HUMIDITY

DURING DAYS OF DIFFERENT DAILY RAINFALL CATEGORIES

	BENIN			ENUGU			ILORIN			KANO			SOKOTO		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
June															
25mm.+	29.5	89	3.3	26.5	74	6.9	27.2	68	8.8	23.9	62	14.6	23.6	60	16.0
12-25mm.	28.7	84	4.5	26.7	77	6.1	27.2	76	6.6	22.6	59	15.4	23.0	52	20.9
less 12mm.	28.1	85	4.1	26.7	80	5.5	26.8	76	6.4	23.0	67	11.4	22.4	53	20.0
all rain days	28.6	84	4.6	26.5	76	6.3	27.0	76	6.4	23.8	79	6.3	22.5	53	19.9
no rain days	28.4	85	4.4	25.8	72	7.0	26.2	73	7.0	21.5	71	8.6	22.1	53	19.6
July															
25mm.+	27.5	89	3.1	25.4	72	7.4	26.3	80	5.4	25.6	77	7.6	22.1	54	18.9
12-25mm.	27.9	90	2.7	26.0	70	7.8	25.7	83	5.4	24.0	73	9.2	22.2	53	19.7
less 12mm.	28.0	91	2.6	25.6	73	7.2	25.7	80	6.5	24.5	77	7.2	24.2	73	9.0
all rain days	27.5	89	3.1	25.6	73	7.2	25.7	81	4.2	25.0	78	7.2	23.5	65	12.6
no rain days	26.0	91	2.3	24.6	67	8.2	25.3	79	6.9	24.2	73	9.0	23.2	57	17.3
August															
25mm.+	27.1	87	3.5	25.5	76	6.2	25.2	81	5.9	25.2	77	7.6	24.9	67	12.5
12-25mm.	27.0	90	2.7	26.1	77	6.1	25.0	88	8.3	25.3	84	4.9	25.5	77	7.7
less 12mm.	27.5	94	1.6	25.3	70	7.5	24.5	72	5.7	25.0	82	5.6	25.0	79	6.7
all rain days	27.3	89	2.9	25.5	71	7.3	25.0	73	5.2	25.2	79	6.5	24.9	75	8.3
no rain days	26.2	85	4.0	23.9	63	8.9	23.9	79	6.3	24.2	78	6.9	25.1	71	10.1
Sept.															
25mm.+	28.3	81	5.5	28.1	67	9.4	25.4	77	7.4	25.2	79	6.2	24.2	71	9.6
12-25mm.	28.0	68	8.9	26.7	71	7.7	26.6	83	5.6	24.3	75	8.1	24.7	70	10.3
less 12mm.	28.5	85	4.3	24.8	72	6.9	26.0	84	5.1	24.5	79	5.4	25.2	78	7.0
all rain days	28.3	79	6.1	25.9	73	6.9	26.0	82	5.7	24.6	79	5.3	25.2	76	8.0
no rain days	28.7	80	5.7	26.3	72	7.5	25.8	76	8.0	24.4	72	9.4	24.8	61	15.7

Key to Columns: (1) Mean Daily Vapour Pressure (mb.), (2) Mean Daily Relative Humidity (%), (3) Mean Daily Saturation Deficit (mb.)

TABLE THREE

DAILY POTENTIAL EVAPOTRANSPIRATION

DURING PERIODS OF DIFFERENT DAILY RAINFALL CATEGORIES

	BENIN			ENUGU			ILORIN			KANO			SOKOTO		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
June															
25mm+	40	2.9	2.9	37	2.8	2.3	46	4.9	4.8	29	4.8	4.0	47	5.9	5.0
12-25mm.	17	2.7	2.6	18	2.5	1.9	13	4.1	4.0	15	5.5	5.1	23	6.0	4.4
less 12mm.	5	2.8	2.8	5	3.1	3.0	3	3.5	3.2	5	4.6	4.3	3	6.9	5.2
all rain days	16	2.8	2.7	13	2.9	2.6	12	4.0	3.7	9	4.0	4.3	12	6.7	5.1
no rain days		3.2	3.4		3.6	3.5		4.1	4.0		4.3	4.5		6.8	5.2
July															
25mm.+	57	2.0	1.7	47	3.0	2.5	38	3.1	2.7	41	4.7	4.9	38	6.2	3.9
12-25mm.	18	2.2	2.0	16	2.9	2.3	18	2.9	2.5	21	4.7	4.8	18	6.6	4.9
less 12mm.	15	2.1	2.0	4	2.8	2.3	1	3.3	2.7	4	3.3	2.8	4	4.2	4.1
all rain days	19	2.2	2.0	14	2.9	2.3	13	3.1	2.7	14	3.9	3.7	14	4.9	4.3
no rain days		3.1	3.7		3.6	3.4		3.7	3.5		4.9	5.1		6.2	4.7
August															
25mm.+	38	2.7	2.6	39	2.9	2.5	29	4.2	4.4	37	4.4	4.4	40	4.6	3.4
12-25mm.	16	1.8	1.5	20	2.8	2.3	18	2.5	2.3	18	3.0	2.8	22	4.2	3.9
less 12mm.	3	2.2	2.3	3	3.0	2.4	4	2.7	2.2	9	3.2	2.9	3	3.8	3.5
all rain days	13	2.4	2.4	11	2.9	2.4	12	2.9	2.5	19	3.9	4.1	12	4.0	3.6
no rain days		2.7	2.6		3.3	2.7		3.1	2.7		3.8	3.7		4.7	4.0
Sept.															
25mm.+	45	1.9	1.7	41	3.5	2.7	51	3.5	3.1	33	3.8	3.7	51	4.7	6.5
12-25mm.	18	2.5	2.4	18	3.5	3.1	19	3.1	2.7	14	5.5	4.2	16	5.2	4.5
less 12mm.	7	2.6	2.4	3	3.0	2.6	4	3.1	2.9	4	4.0	4.1	4	3.6	3.3
all rain days	18	2.5	2.2	12	3.1	2.7	14	3.2	2.9	10	3.8	3.7	12	4.1	3.8
no rain days		3.4	3.4		3.9	3.8		3.7	3.2		4.9	4.8		5.4	4.8

Key to Columns: (1) Mean Rain per Rainy Day, (2) Potential Evapotranspiration using Penman Formula, (3) Potential Evapotranspiration using Davies Formula in the savanna and that of the region to the south. Although there tends to be a not unexpected decrease in the total quantity of rain as one goes northward, the relative totals brought by falls of different categories and the balance of rainy days are very much the same. Thus, in general one can say that between 50% and 60% of the total rain comes in falls of over 25 mm, representing between 20% and 25% of the total days of rain at both savanna and non-savanna stations in comparable months. Likewise some 50% to 60% of rainy days tend to be in the under 12 mm category, which between them produce 25% or less of the total rain. There tends to be more rain at Benin, the sole forest station in the table, than at the two savanna stations, but this is to be expected. One feature of this rainfall difference, however, is that the biggest contrasts seem to be in respect of rainfalls exceeding 25 mm; the totals of the lower categories are not so very different. The overall result of considering daily rainfall by categories, however, is to draw attention to the likenesses between the savanna stations and those to the south, thus tending to confirm the general conclusion stated earlier concerning the similarity in wet season conditions between the forest and the savanna.

This impression of similarity begins to break down however when attention is turned to the tables depicting atmospheric humidity on the one hand (Table Two) and that indicating potential evapotranspiration on the other (Table Three). In the former table, the savanna stations remain generally similar to Enugu and Ilorin in the southern transition zone, but can be seen as clearly different from Benin. At the latter station, atmospheric humidity is high from whatever angle we regard it and whatever the category of rainfall. Only in September is there an indication of lower humidity values, especially in the 12 mm to 25 mm rainfall class. By contrast, Kano and Sokoto display drier atmospheric conditions, which are expressed in all humidity categories but are particularly noticeable in terms of saturation deficit which, like those at Ilorin and Enugu as well, are commonly double those at Benin for both non-rainy days and all classes of days with rain.

But if the savanna stations unite with those of the southern transition in their atmospheric humidity contrasts with Benin, they display unique features when potential evapotranspiration is examined (Table Three). This element was calculated by two formulae: that of Penman (Penman, 1948) and that of Davies (Davies, 1969). Both methods show that when the evaporating energy forces are added to atmospheric humidity, the savanna stations become portrayed as distinctly different from both Benin and the southern transition stations. One can say that at Kano, and Sokoto, whatever the class of rainfall day, potential evapotranspiration generally equals or exceeds 3.0 mm a day, whereas elsewhere the common figure for rainy days during the principal rainfall months is lower than this. This contrast carries over into days without rain as well, though perhaps not quite so strongly. Thus, at Kano in July and August the mean potential evapotranspiration for all rainy days is close to 4.0 mm in both months and the corresponding figures at Benin for July and September lie between 2.0 mm and 2.5 mm and at Ilorin for the same two months they are about 3.0 mm. On the other hand, the mean potential evapotranspiration for rainless days at Kano in July is 5.0 mm and in August is 3.8 mm which compares with corresponding figures in the region of 3.5 mm at Benin and similar ones at Enugu and Ilorin.

There is, however, another notable feature characteristic of Kano and Sokoto which is not repeated at the other stations shown in Table Three. It is the comparatively high potential evapotranspiration of rainy days having more than 25 mm. In both July and August this is over 4.0 mm, except at Sokoto under the Davies formula. Moreover, the value of potential evapotranspiration in this rainfall class commonly equals or exceeds that of non-rainy days and is, indeed, also higher than nearly all the other rainy day classes of either month. Such a feature is found only at Ilorin in June and August among the analyses for the other stations. It has already been shown that at all stations most of the rain, commonly more than 50%, comes on days with more than 25 mm. In other words, at the savanna stations, more than half the rainfall tends to be associated with the highest rates of potential evapotranspiration during a wet season month, and these rates are one and a half to two times those of the higher rainfall days elsewhere. Perhaps this single fact indicates the most notable way in which savanna moisture conditions differ from those of the area to the south.

Further substance to these distinguishing elements of the savanna is given by examining conditions on individual days. An extensive sample of these could not be undertaken owing to the limited data available. However, it proved possible to obtain photo or microfilm copies of a number of autographic charts of temperature, relative humidity and precipitation for several stations. From these a selection was made to illustrate the conditions of individual days for the different categories grouped in the preceding tables. It was not possible to calculate potential evapotranspiration

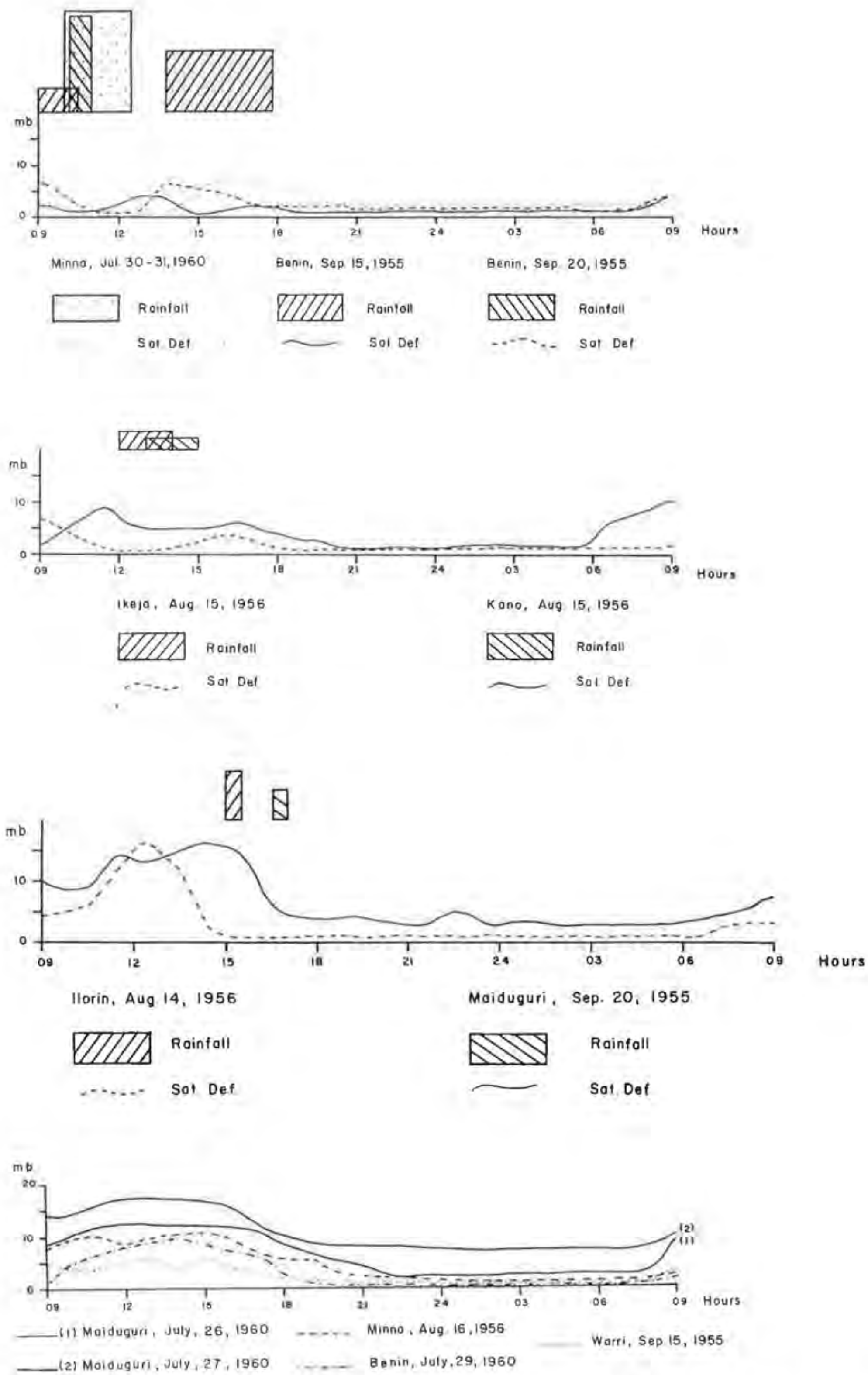


Fig. 2 Precipitation and Saturation Deficit of Individual days

for these days since the necessary data of sunshine or radiation required in any acceptable formula for detailed work were not available. In any case these formulae are intended for periods somewhat longer than a day. Nevertheless, by calculating saturation deficit from the available data an idea of the drying power of the air can be obtained and the contrasts that exist between the savanna and the non-savanna, may be further illustrated. The results of such analyses are shown in Fig. 2. This figure consists of examples of situations during the three categories of rainfall of more than 25 mm, 12-25 mm, and less than 12 mm and a fourth diagram is for selected days when no rain was recorded.

In all instances, it is clearly seen that the savanna stations have a much higher value of saturation deficit as compared with stations to the south, whatever the rainfall category may be. Generally the duration of relatively high saturation deficit for a longer period is associated with stations located in the savanna. Moreover, rapid recovery to a high saturation deficit after the rain ceases is a particular characteristic of savanna stations, on days with more than 25 mm of rainfall. On the contrary, in the forest (represented by Benin) the higher saturation deficit is associated with the day which had the lower rainfall of the two days shown. The graph for rainless days is largely self explanatory, portraying the systematic decrease of saturation deficit southwards, from the savanna into the forest.

Further light may be thrown on the moisture conditions revealed in the foregoing analyses by examining Nigeria's basic climatology and synoptic features. The location of the country between the desert to the north and ocean to the south exposes different parts of the country at times to the

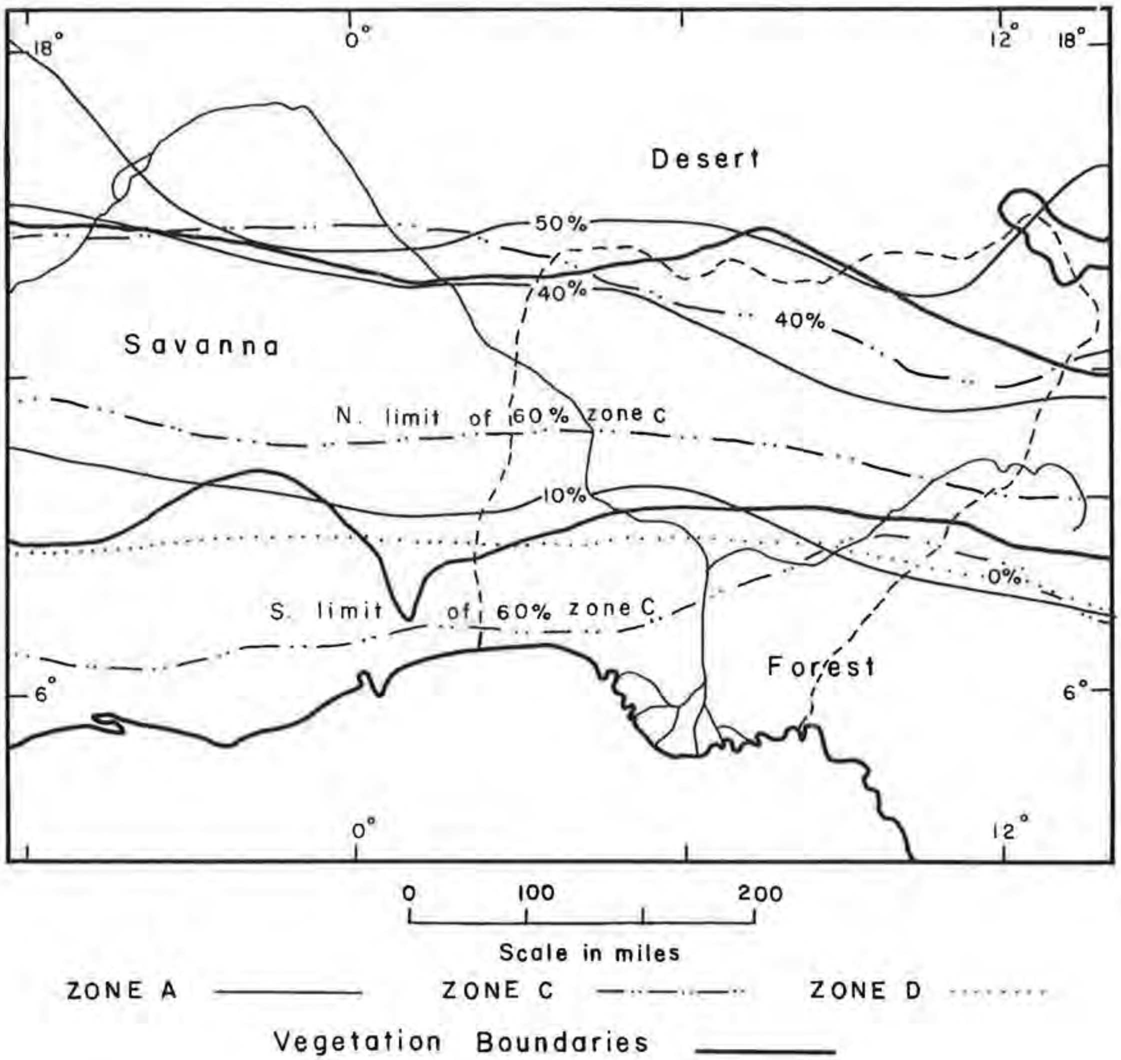


Fig. 3 Duration of Different Weather Zones over Nigeria

Note: This map was prepared by analysing the daily position of the SD as shown on synoptic charts , and plotting its daily location in squares of 5° lat. and long. A full explanation is given in Swami, 1970, see also Garnier 1967.

moist air from the south and at times to the dry air from the north (Trewartha, 1961). Where the two airstreams meet a zone of discontinuity is formed, which has been referred to as the surface discontinuity (SD) by Garnier (1967), but is also widely known at the Inter Tropical Convergence Zone (Flohn, 1960). The seasonal migrations of the SD, conditioned by the seasonal movement of the sun, causes the formation of different weather zones. Contrasts in both a vertical and a horizontal sense on either side of the SD lead to the formation of distinctive weather zones the locations of which fluctuate in relation the varying positions of the SD (Garnier, 1967). These zones may be summarized briefly in a north to south direction as comprising: Zone A, which is north of the SD and is predominantly dry; Zone B, immediately south of the SD and characterised by low level dampness and dry air at upper levels; Zone C, where the depth of moist air permits the development of clouds in the unstable atmosphere and hence forms the major zone of precipitation; and zone D, in which the upper air stability tends to inhibit upper air movement and consequently decreases convective effects and tends to reduce the amount of precipitation despite high humidity and generally overcast conditions.

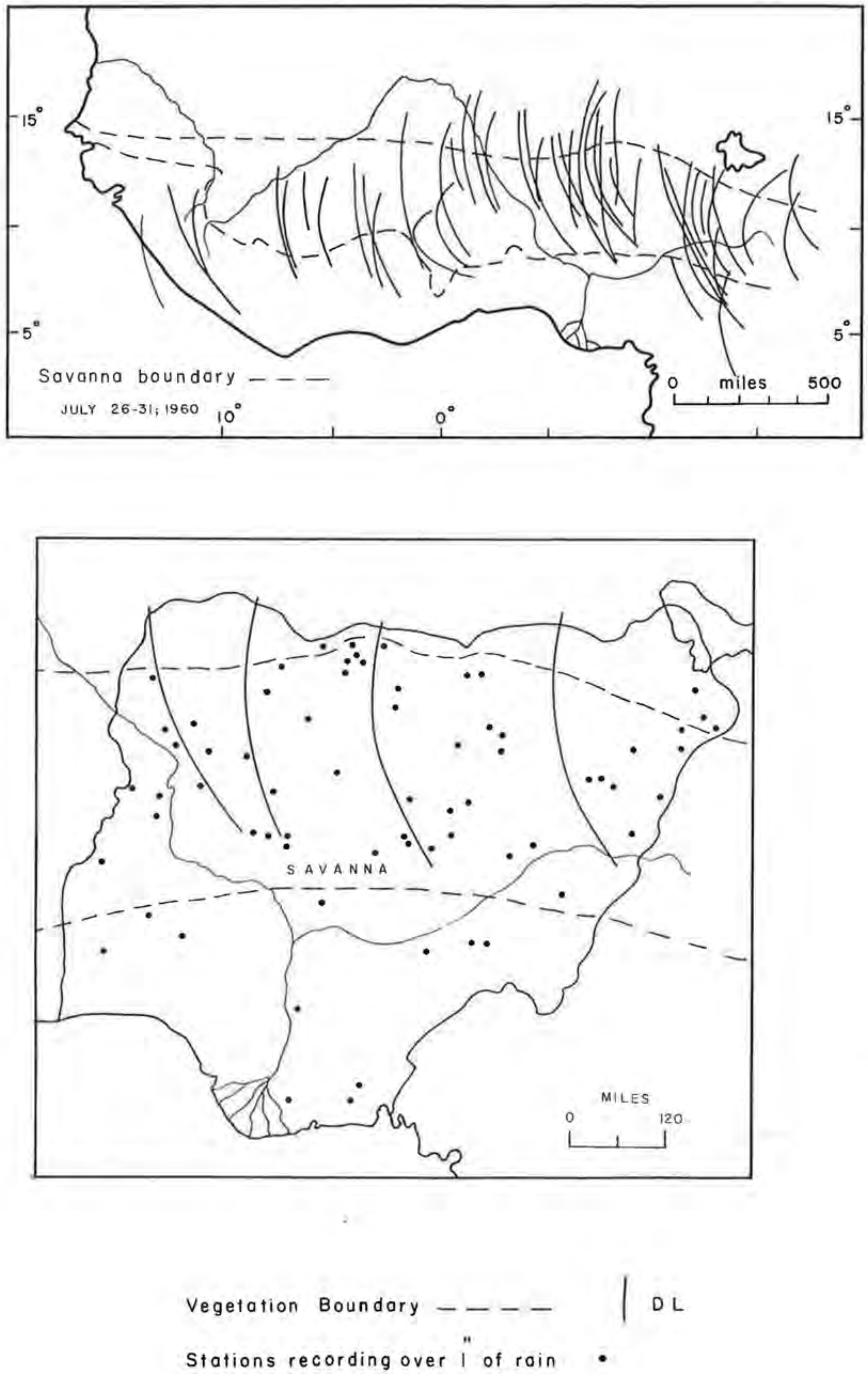
Since the weather zones produce correspondingly distinctive precipitation conditions, it seems reasonable to think that an analysis of their varying positions may contribute to an understanding of the difference in moisture conditions between the forest and the savanna. The results of such an analysis are given in Fig. 3. From this figure it is apparent that the influence of Zone C is felt between 40% - 60% of the year throughout most of the savanna region but with a frequency higher than 60% in the southern part. At times other than the rainy season the savanna is largely dominated by Zone A. By contrast the forest areas to the south experience little Zone A weather, and are predominantly affected by conditions in zones B, C, and D. Insofar as rainy season conditions are concerned it follows that the savanna experiences mainly the rainfall characteristic of zone C, especially its northern part, whereas at this time the forest is experiencing either southern zone C or else zone D rainfall and humidity characteristics.

Zone C is pre-eminently the weather zone where disturbance lines are active and the greater part of the rain in this region is brought about by these phenomena. These disturbance lines consist essentially of a line of thunderstorms which move in a generally east to west direction at a speed of 25-30 mph (Eldridge, 1957). The rainfall along them is localised and short in duration, but is also heavy. Characteristically 70% - 80% of the total rainfall comes in the first 10% - 15% of the time of the fall (Garnier, 1953). After the passage of the disturbance line there is a rapid return to drier conditions. There may be an hour or two of cloudiness but this is not always so. It is characteristic of disturbance lines that their southern part is often mingled with a large area of widespread rain brought by scattered thunderstorm activity within a region of generally overcast skies and high humidity (Eldridge, 1957). Any rainfall occurring in zone D also tends to fall into a similar category.

Because the savanna region is predominantly the area covered by zone C and especially by its northern part its rainfall is particularly closely associated with that part of the disturbance lines where thunderstorm activity predominates but passes quickly. By contrast the area to the south of the savanna is one in which, during the rainy season, high humidity and extensive periods of cloudiness prevail. This situation results partly from the predominance of the humid air moving in from Atlantic sources. It is also closely connected with the disturbed region of rain and cloudiness at the southern ends of the disturbance lines.

The relationship of the disturbance lines to the savanna region during the middle of the rainy season is illustrated in fig. 4. The figure, indicates the position of all the disturbance lines irrespective of date and time which traversed West Africa from July 26th to 30th, 1960 inclusive, according to the West African synoptic charts prepared at three hourly intervals at Ikeja airport, Lagos (fig. 4(a)), and also shows the distribution of rain over Nigeria for one individual day - July 30th, 1960 and the passage of the disturbance line associated with it (fig. 4(b)). On both figures the boundaries of the savanna region have been marked. This region seems quite clearly located squarely within the zone of passage of the disturbance lines. In particular, the southern ends of these lines of atmospheric instability coincide closely with the southern boundary of the savanna area.

It seems, therefore, that the rainy season in the savanna must, in fact, be regarded as somewhat different from that of the region to the south of it, despite the apparent similarity given to it by the rainfall figures. This difference is clearly a consequence of different potential evapotranspiration rates, which are themselves a reflection of differences in the actual nature and duration of the rainfall and associated synoptic systems. This difference in the character of the savanna may be quite significant ecologically. Potential evapotranspiration is often held to be a good indicator of growth rate. Under conditions of high potential evapotranspiration,when water is non-limiting, the rate of plant growth



(a)

(b)

Fig. 4 The Relation of the Savanna Region to Disturbance Lines in Nigeria may well be strong. There is clearly no question of a water shortage during the short and reliable savanna wet season. The statistics given in Table Three for example, show that the water balance for each rainfall category is always positive. Thus it is possible to think that the relatively high potential evapotranspiration of the savanna, particularly on days which bring the majority of the rain, provides a strong stimulus to plant growth. Perhaps this is a major factor in maintaining the vegetation character of the area, and leads to the interesting thought that if the rainy season of the savanna were, in fact, like that of the forest, with its higher humidities and lower potential evapotranspiration, the savanna vegetation might not be so well maintained, and that the region preserves its present character because of wet season differences rather than wet season similarities with its southern neighbour.

Thus the major conclusion suggested by this brief analysis of daily moisture conditions is that there are, in fact, significant ways in which the savanna region in Nigeria is, during the rainy season, distinguished in terms of moisture conditions, and in a climatic sense from the rainy season of adjacent forest areas. The full extent and nature of these distinguishing features, however, can only be adequately appreciated by analysing daily statistics and relating the results to the basic physical processes of the area's climatology. Studies which take a month as their time unit of study tend to mask the realities of the diurnal situation and can well lead to erroneous conclusions concerning the climatic relationships of plants and vegetation regions. It is hoped that this short account of conditions in one part of the tropical world will have illustrated how a study of daily conditions and frequencies can provide a basis for distinguishing moisture characteristics within an area and in an ecological sense, in a way which appears not yet to have been widely used in studies of vegetation regions and plant ecosystems.

REFERENCES

Aubréville, A., 1949: "Climats, Forêts et Désertification de l'Afrique Tropicale", Societé d'éditions Géographiques Maritimes et Coloniales, Paris.

Beard, J.S., 1944: "Climax Vegetation in Tropical America", Ecology, Vol. 25, No. 2, pp. 127-158.

Dansereau, Pierre, 1957: "Biogeography - an Ecological Perspective", The Ronald Press Company, New York.

Davies, J.A., 1969: "A Simple Energy Balance Approach to the Moisture Balance Climatology of Africa", in Environment and Land Use in Africa, edited by M. F. Thomas and G.W. Whittington, Methuen and Co. Ltd., London.

Eldridge, R.H., 1957: "A Synoptic Study of West African Disburbance Lines", Quart.Journ.Roy.Met.Soc., Vol. 83, pp. 303-314.

Flohn, H. 1960: "The Structure of the Inter-tropical Convergence Zone", in Tropical Meteorology in Africa, Proceedings of the symposium jointly sponsored by the WMO and the Munitalp Foundation, Nairobi.

Garnier, B.J., 1953: "Some Comments on the Rainfall at University College, Ibadan during 1952", Research Notes, No. 3, University College, Ibadan, May.

Garnier, B.J., 1967: "Weather Conditions in Nigeria", Climatological Research Series, No. 2, McGill University, Montreal.

Penman, H.L., 1948: "Natural Evaporation from Open Water, Bare Soil and Grass", Proc.Roy.Soc.Lond., Vol. 193, pp. 120-145.

Russell, R.J., 1934: "Climatic Years", Geogr.Rev., Vol. 24, pp. 92-103.

Swami, Kala, 1970: "Moisture Conditions in the Savanna Region of West Africa", M.Sc. Thesis, McGill University, Montreal.

Tansley, A.G., 1935: "The use and abuse of vegetational concepts and terms", Ecology, Vol. 16, pp. 284-307.

Thornthwaite, T.W., 1931: "The Climate of North America According to a New Classification", Geogr.Rev., Vol. 21, pp. 633-655.

Trewartha, G.T., 1961: "The Earth's Problem Climates", University of Wisconsin Press, Madison.

RESEARCH REPORT

Previous numbers of this BULLETIN have contained references to a remote sensing experiment to measure surface radiation temperatures from a light aircraft (see BULLETIN no.6, pp. 61-62 and BULLETIN No.7, pp.30-33). The purpose of the present report is to offer more information on the instruments and methods used, and to indicate some of the results obtained.

The instrument used was a PRT-5 (Precision Radiation Thermometer) supplied by the Barnes Engineering Company. It consists of an optical head, an electronic control unit, and interconnecting and power cables. The optical head collects infra-red radiation from the target surface and generates an electrical signal which is proportional to the difference between the radiation from the surface and that from a precisely temperature-controlled internal black-body source. This signal is further processed to produce a DC signal which is displayed on a panel meter graduated in absolute temperature units and which can also be fed into a recorder unit. A system of lenses and filters in the optical head controls the spectral range observed by the optical head. The normal instrument has a spectral range of 8-14μ, but narrow band filters are also available: in Barbados one of the instruments used observed in the range 10-12$_{\mu}$, thus enabling observations on the effect of atmospheric attenuation to be made (BULLETIN No.7,pp.30-33). A 2^{o} field of view was used, giving a target area 35ft. in diameter from a distance of 1000 ft.

For airborne observations each PRT-5 optical head was mounted in a cylindrical housing approximately 12 ins. high and 6 ins. in diameter. A right-angled bracket was fixed to the outside of the housing, with two bolt holes in it. This enabled the housing to be bolted to the step of the aircraft by means of two holes drilled in the aircraft step. The leads from the optical head entered the aircraft through the window, and was attached to the PRT-5 recording unit and recording was made on DL620A Digital Data System supplied by Metrodata Systems Inc. of Norman, Oklahoma. The recording apparatus was installed in the luggage compartment of the aircraft in a position from which it could be easily controlled by an operator.

Cessna aircraft were used for the experiment. A four seater 172 aeroplane was used for one period and for another a two-seater 150 was used. Of the two the smaller aircraft seems more suitable for this kind of work. The pilot has a better view of the ground from it than from a 172, and is thus able to pass more accurately over ground truth stations and other check points when flying without the aid of instruments.

Calibration of the PRT-5 was undertaken before and after each flight. This calibration referred to two relationships: the temperatures indicated on the instrument dials in relation to the millivolt record of the DL620A data system, and the relation of the PRT-5 readings to a mercury thermometer in calibration water baths. Each flight, therefore, can be said to have its individual instrument calibration. A composite analysis of results, however, shows that over each experimental period it is possible to use straight line regression equations in respect of the calibration relationships for each experimental period. The relevant regression equations used, and their correlation coefficients (all at greater than 95% confidence levels) are as follows:

(1) PRT-5, 8-14 μ, June.

(a) PRT dial temp.°C (X) to DL620 A mv. reading (y)

$Y = -304.37 + 26.99\ X \qquad R = 0.998$

(b) PRT dial temp.°C (X) to Water Bath temp.°C (Y)

$Y = -9.496 + 1.333\ X \qquad R = 0.979$

(2) PRT-5, 8-14 μ, December:

(a) PRT dial temp.°C (X) to DL620 A mv.reading (Y)

$Y = -284.76 + 26.89\ X \qquad R = 0.999$

(b) PRT dial temp.°C (X) to Water Bath temp.°C (Y)

$Y = -1.600 + 1.078\ X \qquad R = 0.999$

(3) PRT-5, 10-12 μ, December:

(a) PRT dial temp.°C (X) to DL620A mv. reading (Y)

$Y = -276.93 + 26.12\ X \qquad R = 0.999$

(b) PRT dial temp.°C (X) to Water Bath temp.°C(Y)

$Y = -0.552 + 1.019\ X \qquad R = 0.999$

In using a PRT-5 for airborne measurements it is important to know the effects of atmospheric attenuation. The use of a narrow band filter will obviously reduce this effect in comparison with the use of a standard instrument observing in the 8-14 μ, range. The results of the atmospheric attenuation experiments made in Barbados, however, show that in both cases there is a linear relation between the measured and true surface values when airborne measurements are made below 3,500 ft.(Weiss,1970). At these altitudes the errors were as follows:

PRT-5, 10-12 μ	-0.54°C/1,000 ft.
PRT-5, 8-14 μ	-0.80°C/1,000 ft.

It would appear, therefore, that calibration for atmospheric attenuation can be effected before and after observation flights by making two flights below 3500ft. at different altitudes (say, 1000ft. and 2000ft.) above a steady target such as a water surface and extrapolating the data to ground level.

The PRT-5 is a fast response instrument of high sensitivity, capable of recording temperatures to within 0.1°C. Thus, surface variations due to the passage of a cloud, or a change in surface wind conditions, are registered by the instrument as well as variations due to small changes in the physical character of the surface itself. When these data are recorded on a magnetic tape system such as the DL620A, which has a capability of 48 observations a second, the interpretation and analysis of results becomes an exacting task, unless all that is required is a generalised, mean value across an area. In the present case, however, the objective is an evaluation of topographic variations in surface radiation temperatures and, subsequently, long-wave radiation emission. It is thus necessary to identify the surface in such a way as to distinguish field boundaries, changes of gradient and altitude, and the influence of roads and groups of buildings. All this diversity is readily reflected in the data:but then so are the passage of clouds, or changes in wind speed, so that it is extremely difficult and at times impossible to distinguish surface from atmospheric influences in the data obtained.

Three analysis procedures have been adopted:(a) Areas of uniform land use were chosen over which the aeroplane would take several seconds to fly. The proportional distances of the boundaries of these land-use areas between surface check-points, identifiable on the record by a coding system, were noted. The lines of print-out data clearly within a given land-use area were then identified by proportional calculation.

(b) With the aid of air photographs and by inspection of the data and flight notes, distinctive roads or groups of buildings were identified in the data record. Analysis was then effected for a specified number of seconds before and after these identification points, from which surface radiative temperatures of given types of terrain could be obtained.
(c) Temperature cross-sections, using clearly identifiable surface changes such as a coastline as key points, have been prepared by sampling data at intervals corresponding to short distances on a base map. The cross-sections can then be fitted to the map to provide temperature profiles. This technique is particularly good for areas near coasts or water bodies, and also where urban influences make marked contrasts with the rural countryside.

Results from these analyses are not yet sufficiently advanced to draw meaningful conclusions. In general it would appear that the surface variations of temperatures over a rural area yield long-wave radiation emission values which lie within $\pm$ 5% of those observed at a single base station representative of the area in question. The radiation from water bodies and urban areas, however, lie outside these limits and it is too early yet to say if the remote sensing experiment has offered a way for rationally evaluating the topographic variation of long-wave radiation to a comparative degree of accuracy to that already established for short-wave radiation (Garnier and Ohmura, 1969).

Since the publication of the last number of this BULLETIN work in urban studies in Montreal and on the radiation balance at Mont St.Hilaire has continued. The greater part of this has concentrated on the analysis of data from earlier experiments and will be reported on more fully at a later date. New experimental work in both these fields which is just commencing at the time of writing this report comprises:
(a) comparative measurements of the long-wave and short-wave radiation balances over grass and over a forest canopy at Mont St.Hilaire; and
(b) the investigation of the comfort index and wind chill in downtown Montreal. Long-wave radiation studies in Mont St.Hilaire and vicinity can be expected to expand substantially over the next 12 months with the arrival (expected in October) of a PRT-5 recording unit and housing for attachment to a light aircraft obtained with the aid of an NRC major equipment grant.

B.J.Garnier,
Principal Investigator.

References

Garnier,B.J. and Atsumu Ohmura, 1970:"The Evaluation of Surface Variations in Solar Radiation Income", Solar Energy, Vol.13, pp.21-34.

Weiss, M, 1970:"A Report on Airborne Measurements of Earth Surface Temperature (ocean and land) in the 10-12μ regions", Barnes Engineering Company, Stamford, Conn.

NEWS AND COMMENTS

An informal meeting of persons interested in climatology was held at the University of Windsor on Februarv 27-28. The meeting came about through the initiative of Professor Kenneth Hare and the location through the hospitality of Professor Marie Sanderson and the University of Windsor. Discussions roamed the field of climatology, the training of climatologists, and job opportunities. Dr.Heinz Lettau presented an address on the idea of"Climatonomy" . The groups decided to style itself "Friends of Climatology" and to meet once a year. A meeting at MacMaster University is planned fcr 1971.

Dr.T.R.Oke has now left McGill University to take up an appointment in the University of British Columbia. His place at McGill has been taken by Mr.R.G.Wilson, a graduate in climatology from McGill University and currently completing his Ph.D. dissertation for presentation at MacMaster University.

Professor B.J.Garnier attended the Tropical Meteorology Symposium held at the University of Hawaii, June 2-11. He chaired the section on General Climatology, and also presented a paper on "Topographic Variations of Radiation in Barbados".

Kala Swami has been awarded the M.Sc. degree in Geography (Climatology). Her thesis was entitled "Moisture Conditions in the Savanna Region of West Africa".

David Frost a graduate in Geography (Climatology)of McGill University has returned to Canada to join the staff of the University of Saskatchewan at Regina, after completing his doctoral work in climatology at the University of Birmingham, England.

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