

ESTIMATING FREQUENCIES OF DAILY AMOUNTS OF GLOBAL RADIATION OVER AUSTRALIA

by J. D. Kalma.

Division of Land Research, C. S. I. R. O., Canberra, A. C. T.

(Manuscript first received July 1970, in amended form September 1970)

ABSTRACT

Following a method outlined by Liu and Jordan (1960) a nomogram is presented, from which the statistical distribution of daily global radiation* for each month at any Australian locality can be estimated when the long-term monthly average of global radiation is known. One hundred months of daily global radiation records were used for the development of the nomogram, covering 5 recent years at seven Australian actinograph stations.

Predicted distributions for two months at two north Australian stations not used in developing the nomogram were in good agreement with the observed frequency distributions using 5 years of records. Good agreement was also found between predicted cumulative frequency distributions for June and December at Darwin, Alice Springs and Melbourne and those reported by Loewe (1956) for these months and localities.

1. INTRODUCTION

It was reported by Liu and Jordan (1960) for 27 widely separated north American localities (latitude 19° - 55° N; elevation 11-8400 ft above M. S. L.) that the statistical distribution of daily global radiation for a certain month expressed as a fraction of mean daily extra-terrestrial radiation, can be predicted sufficiently accurately for many practical purposes, from the ratio of mean daily global radiation at the surface to mean daily extra-terrestrial radiation. A set of generalized monthly accumulated frequency distribution curves for daily global radiation was subsequently produced. It is clear from both the original frequency distributions and the generalized curves that daily totals of global radiation are not normally distributed. Means and standard deviations therefore do not completely describe these distributions.

Surprisingly, no independent verification of these findings, or use of the generalized distribution curves elsewhere, has to the best of the author's knowledge been reported in the literature despite their great potential value.

* Global radiation is the sum of radiation directly from the sun and indirectly from the sky and is contained in the short wave-lengths from 0.15 to 4.0 μ . In this study the energy received by a horizontal surface per unit time (radiant flux) is expressed in ly/day.

This paper examines the approach of Liu and Jordan (1960) to determine whether a set of generalized distribution curves can be derived for Australian conditions. It is evident that such information could be of great use to workers in the field of agrometeorological and hydrological research and in the possible use of solar energy for domestic and industrial purposes.

Between 1953 and 1968 a network of seven Robitzsch bimetallic actinographs was in operation in Australia and the Territories (Albrecht, 1956). Hounam (1963, 1969) has developed regression equations for estimating global radiation over Australia from cloudiness and sunshine observations which are based on this network.

Since 1967 a new network of 20 Eppley-pyranometer stations (Jesson, 1970) has gradually replaced the actinograph network, but it will take several years before more accurate data are available. Information on spatial distribution of monthly averages of daily global radiation will certainly be more reliable in the next few years, but the statistical distribution of global radiation could remain extremely difficult to predict at places other than the pyranometer stations.

2. METHODS AND RESULTS

The average monthly global radiation (\bar{Q} ly/day) has been calculated for all seven stations of the actinograph network for all available years and from the last 5 years of records. The name, coordinates and elevation of each station have been listed in Table 1. The first value for each month for each station is the overall average, the second value the 5-year mean. Values of the mean daily extra-terrestrial radiation (\bar{Q}_A ly/day) for the various latitudes and all months were read from tables prepared by McCullough (1968). They can also be obtained from graphical representations such as Fig. 1. Eighty four values of \bar{Q}/\bar{Q}_A were calculated, ranging between 0.426 (Rabaul, January) and 0.736 (Darwin, July), using 5-year averages since both averages are sufficiently close to justify use of the last five years only in the subsequent analysis. Twenty months were selected covering the full range of \bar{Q}/\bar{Q}_A values encountered. They have been indicated in Table 1, by italicizing their 5-year averages of \bar{Q} . Corresponding \bar{Q}/\bar{Q}_A values for these months are given between brackets.

About 150 daily totals of global radiation (Q) were available for each selected month (Bureau of Meteorology, 1966, 1970). For all months the period 1964-1968 was used, except for December at Alice Springs where December 1966 and 1967 were not available and December 1962 and 1963 have been used instead.

Accumulated frequencies, f , were calculated ($0 \leq f \leq 1$) for Q/\bar{Q}_A in 40 steps of 0.025, and graphical presentations of the cumulative frequency distributions for all 20 months were produced. Examples of these accumulated frequency distributions are presented in Figs. 5A and 5B. Note that each value of f gives the number of days relative to the total number of days used in the sample on which Q/\bar{Q}_A is less than or equal to a certain value between 0 and 1. As illustrated in Fig. 5 all frequency distributions (one for each value of \bar{Q}/\bar{Q}_A) were slightly smoothed by eye-fitted curves.

Table 1. Monthly averages of global radiation (ly/day) for all years of records (first column) and for the last five years of records (second column) at the seven stations of the Australian actinograph network. Months selected for analysis are indicated by the ratio of mean daily global radiation to mean extra-terrestrial radiation (italicized values).

Month	Rabaul		Darwin		Townsville		Alice Springs		Perth		Williamstown		Melbourne
	T. P. N. G.	N. T.	N. T.	Qld.	N. T.	N. T.	W. A.	N. S. W.	N. S. W.	Vic.			
	Lat. 4°13', Long. 152°11', Elev. 20 ft 1956-68	Lat. 12°26', Long. 130°52', Elev. 88 ft 1953-68	Lat. 19°15', Long. 146°46', Elev. 13 ft 1953-68	Lat. 23°48', Long. 133°53', Elev. 1790 ft 1953-68	Lat. 31°56', Long. 115°57', Elev. 49 ft 1953-68	Lat. 32°49', Long. 151°50', Elev. 13 ft 1953-68	Lat. 37°49', Long. 144° 58', Elev. 170 ft 1953-68						
Jan	422 382	428 419 (.440)	505 509	621 620	649 652	528 525	581 571						
Feb	426 403	453 448	490 502	610 608	596 583 (.624)	480 503	506 500						
Mar	433 421	479 439	480 475	556 540	490 479	424 415 (.531)	395 411						
Apr	425 415	464 498	460 483	466 464 (.658)	341 321 (.516)	322 342 (.561)	274 281						
May	438 (.548)	468 460 (.640)	385 374 (.581)	379 360	260 273	251 255	177 196 (.485)						
Jun	422 406	463 479	372 371	357 358	213 198 (.475)	214 212	155 157						
Jul	397 (.497)	480 507	400 406	391 402	235 229	254 256	163 169 (.467)						
Aug	442 439	531 539	468 467	467 473 (.731)	320 316	314 316	233 232						
Sep	475 477	558 565	561 564 (.695)	550 545	405 421	415 433 (.617)	328 337						
Oct	463 454	558 552	597 591	592 586	532 517	500 470	422 415						
Nov	435 411	547 587	602 584 (.601)	619 603	620 597	565 546	494 503						
Dec	385 (.430)	472 463 (.486)	589 559	621 594 (.582)	665 646	549 551	541 529						

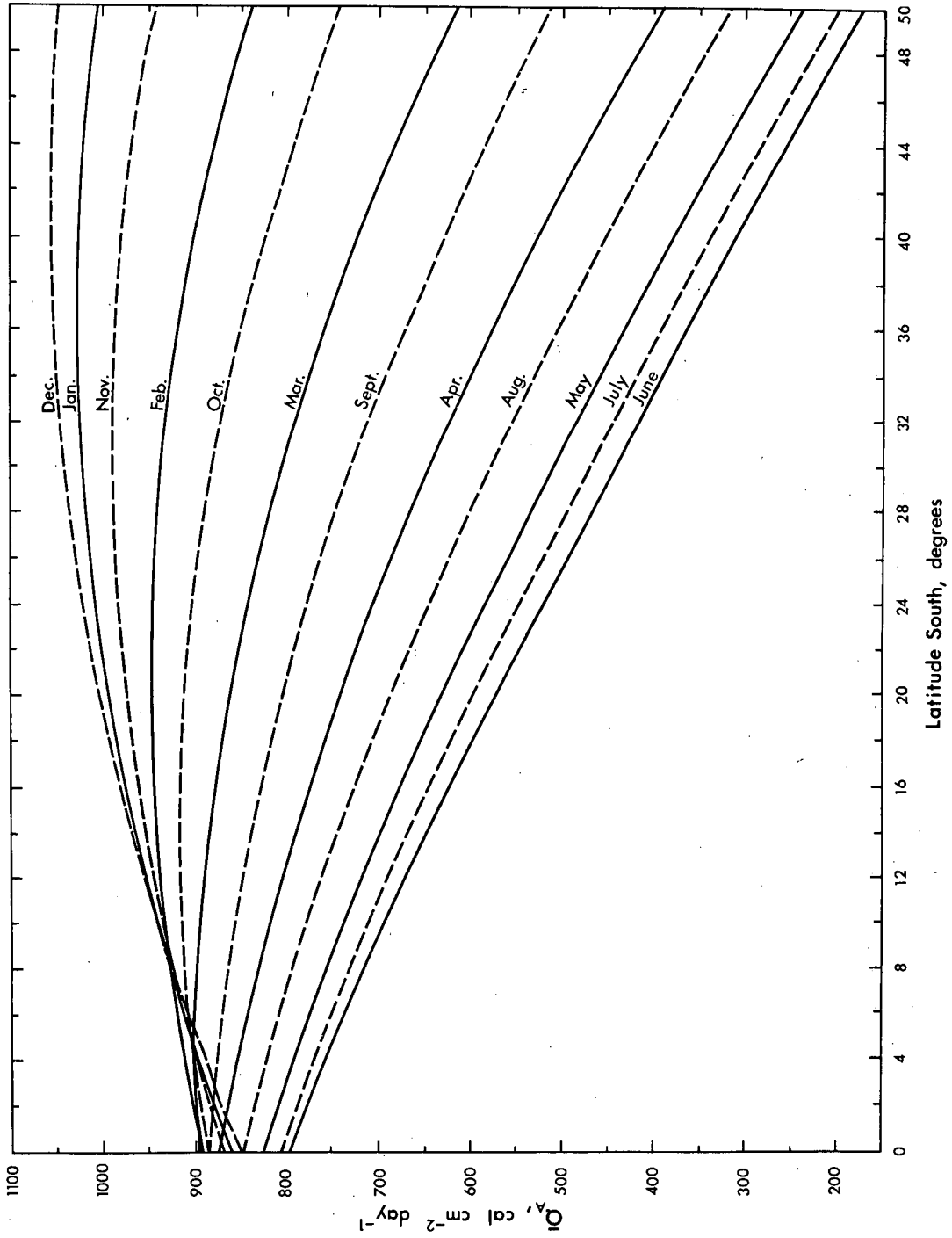


Fig. 1 Mean daily extra-terrestrial radiation \bar{Q}_A received on a horizontal surface for 0-50° South latitude

From all 20 frequency distribution curves, Q/\bar{Q}_A was obtained for $f = 0.0, 0.1, 0.2, \dots, 1.0$. These 220 values were consequently used to obtain 11 f -curves, illustrating the interrelationship between Q/\bar{Q}_A and \bar{Q}/\bar{Q}_A . Five of these eye-fitted f -curves ($f=0.1, 0.3, 0.5, 0.7, \text{ and } 0.9$) are presented in Fig. 2, which includes the individual points as well. In Fig. 3, the 11 f -curves are given together. The top 9 curves apparently converge to a point which theoretically should be $Q/\bar{Q}_A = \bar{Q}/\bar{Q}_A = 1.0$ (no depletion of the solar beam). The top ends ($\bar{Q}/\bar{Q}_A > 0.7$) of the curves for $f = 0.0$ and $f = 0.1$ have therefore been directed to this hypothetical point.

The following example illustrates the use of Fig. 3. The average monthly global radiation \bar{Q} for October at Townsville over 1964-68 is 591 ly/day. Mean extra-terrestrial radiation \bar{Q}_A for 19°S is 912 ly/day (see Fig. 1). Entering Fig. 3 with $\bar{Q}/\bar{Q}_A = 0.648$ leads to the prediction that $Q/\bar{Q}_A \leq 0.68$ on 50% of all October days or that the daily global radiation ≤ 620 ly/day on 15-16 days.

3. DISCUSSION

The surprisingly small scatter of points around the eye-fitted f -curves, five of which have been presented in greater detail in Fig. 2, indicate that for each constant value of f a well-defined relationship exists between Q/\bar{Q}_A and \bar{Q}/\bar{Q}_A . This confirms Liu and Jordan's observations (1960). Fig. 4 gives generalized distribution curves for $\bar{Q}/\bar{Q}_A = 0.4, 0.5, 0.6$ and 0.7 as derived from Fig. 3 for Australia. Liu and Jordan's curves for the same four \bar{Q}/\bar{Q}_A values in north America have also been included. It should be noted that agreement between the curves is poor for $\bar{Q}/\bar{Q}_A = 0.4, 0.5$ and 0.6 and fair for $\bar{Q}/\bar{Q}_A = 0.7$. It may be assumed that the four generalized curves of the present study are as representative for Australia as Liu and Jordan's curves are for the north American continent. Fig. 4 indicates that the results obtained for north America are not applicable to Australian conditions and vice versa.

It may be assumed that $f = 1.0$ corresponds to clear days except for very low values of \bar{Q}/\bar{Q}_A . In actual fact only two months are used for $\bar{Q}/\bar{Q}_A < 0.45$, viz. December, Rabaul and January, Darwin. Both months are months of (near) maximum rainfall with a low percentage clear days. Q/\bar{Q}_A is about 0.83 for most other months used in the present analysis with the exception of April and August at Alice Springs and September at Townsville. This indicates that the transmission coefficient for clear days tends to be constant for most latitudes and months with \bar{Q}/\bar{Q}_A between 0.50 and 0.75.

A discussion of regional differences in solar radiation depletion characteristics falls outside the scope of the present paper. It may be stated, however, that in several recent climatological studies (Sellers, 1965; Bridgman, 1969) significant differences were noted in the magnitude of the various components of the radiation balance between corresponding latitudes in both hemispheres.

This method of predicting the statistical distribution of global radiation for Australian latitudes has been tested for Katherine Research Station (KNRS; 14.3°S, 132.2°E) and Coastal Plains Research Station (CPRS; 12.5°S, 131.3°E), two stations not used in deriving the generalized curves of Fig. 3. \bar{Q} -values were obtained from 5 recent years of Kipp-solarimeter records and \bar{Q}_A values were read from Fig. 1. Two months were selected randomly for both stations. The \bar{Q}/\bar{Q}_A ratios for May and November at KNRS were 0.628 and 0.603 respectively. January

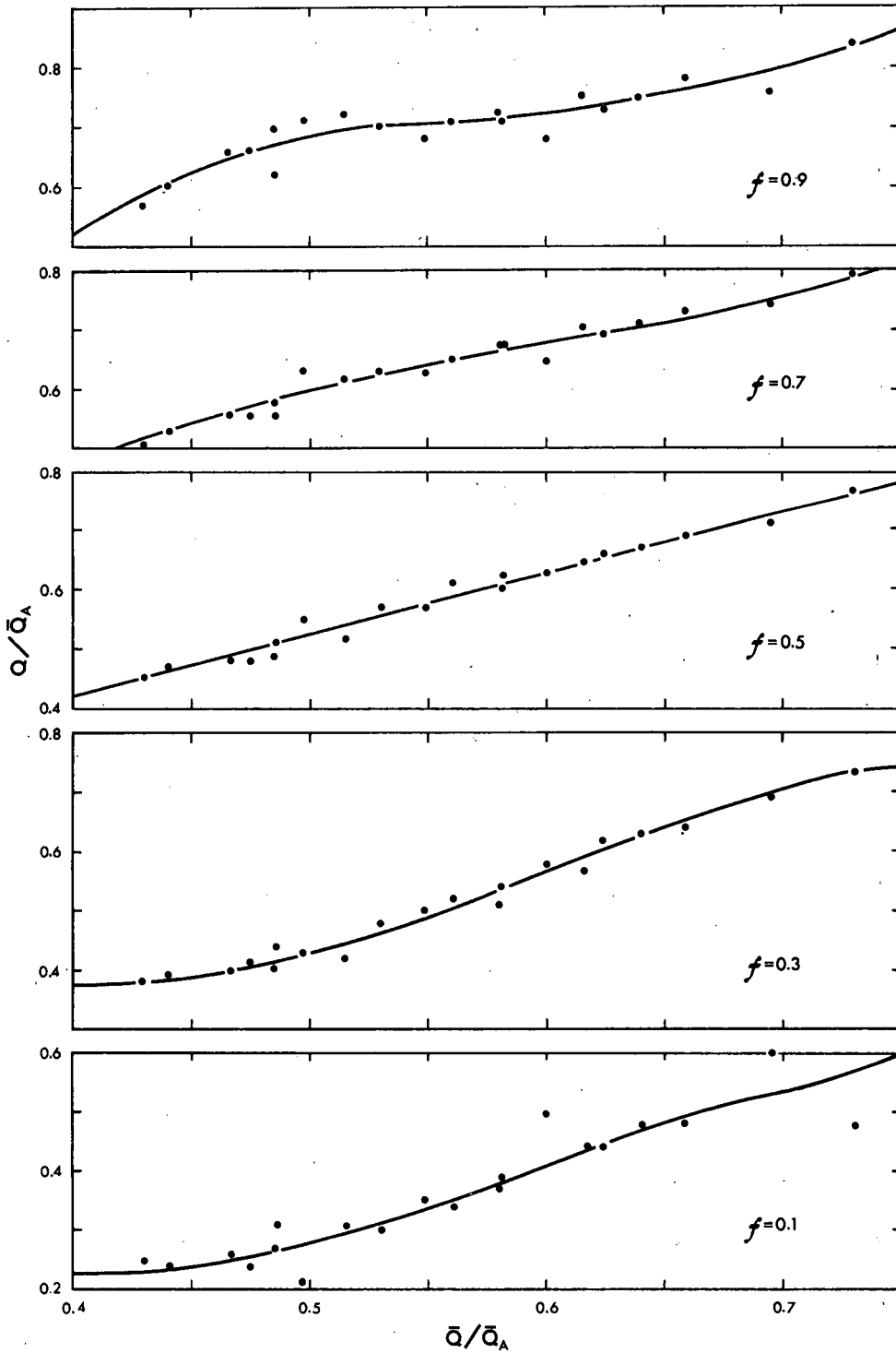


Fig. 2 Empirical relation between daily global radiation (Q) and mean daily global radiation (\bar{Q}), as fractions of mean daily extra-terrestrial radiation (\bar{Q}_A) for five values of cumulative frequency (f).

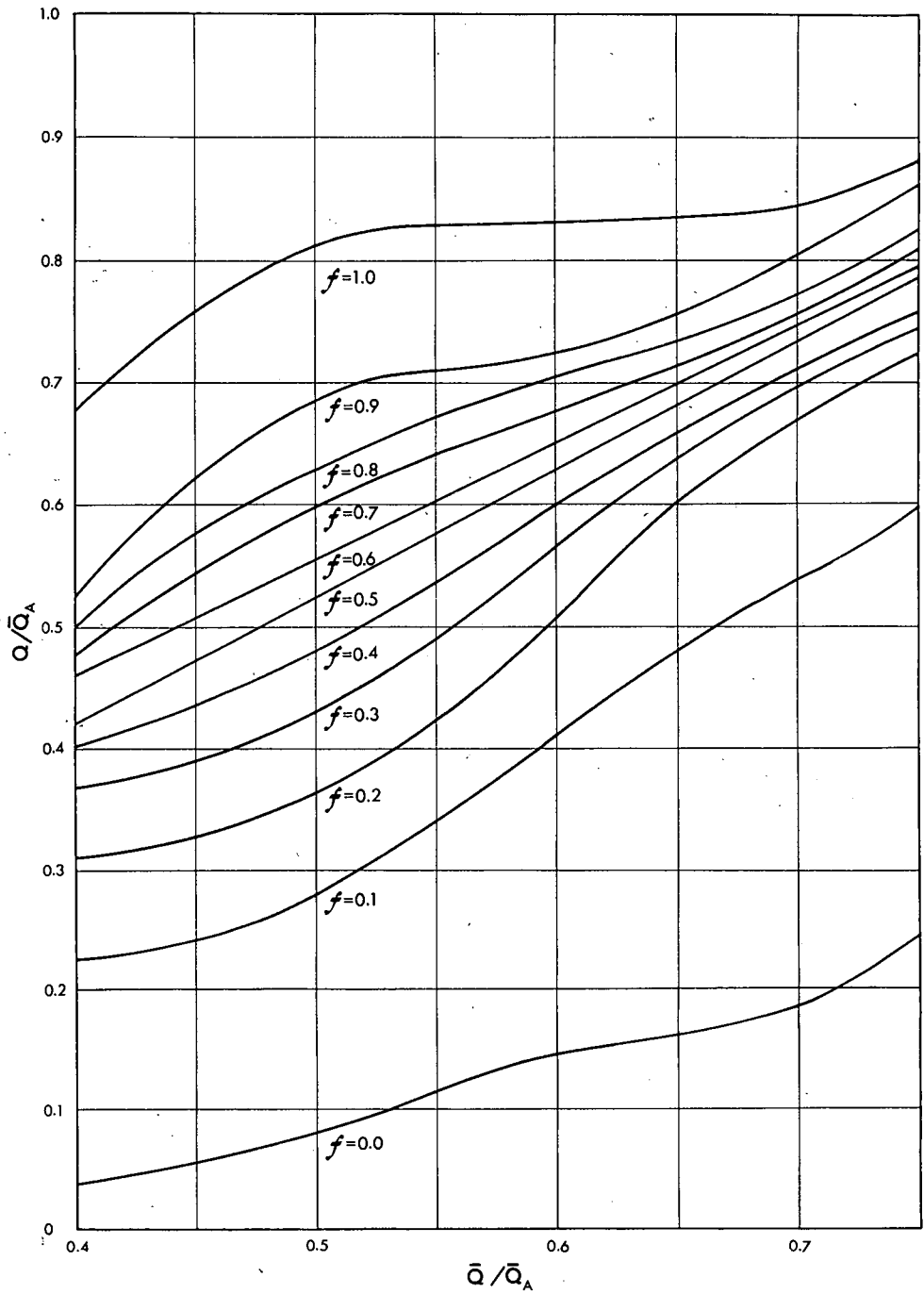


Fig. 3 Nomogram for estimating deciles of the statistical distribution of daily global radiation in Australia or alternatively by interpolation the frequency of occurrence that radiation is equal to or less than a specified value, at different values of the ratio of mean daily global radiation at the surface to mean daily extra-terrestrial insolation (\bar{Q}/\bar{Q}_A).

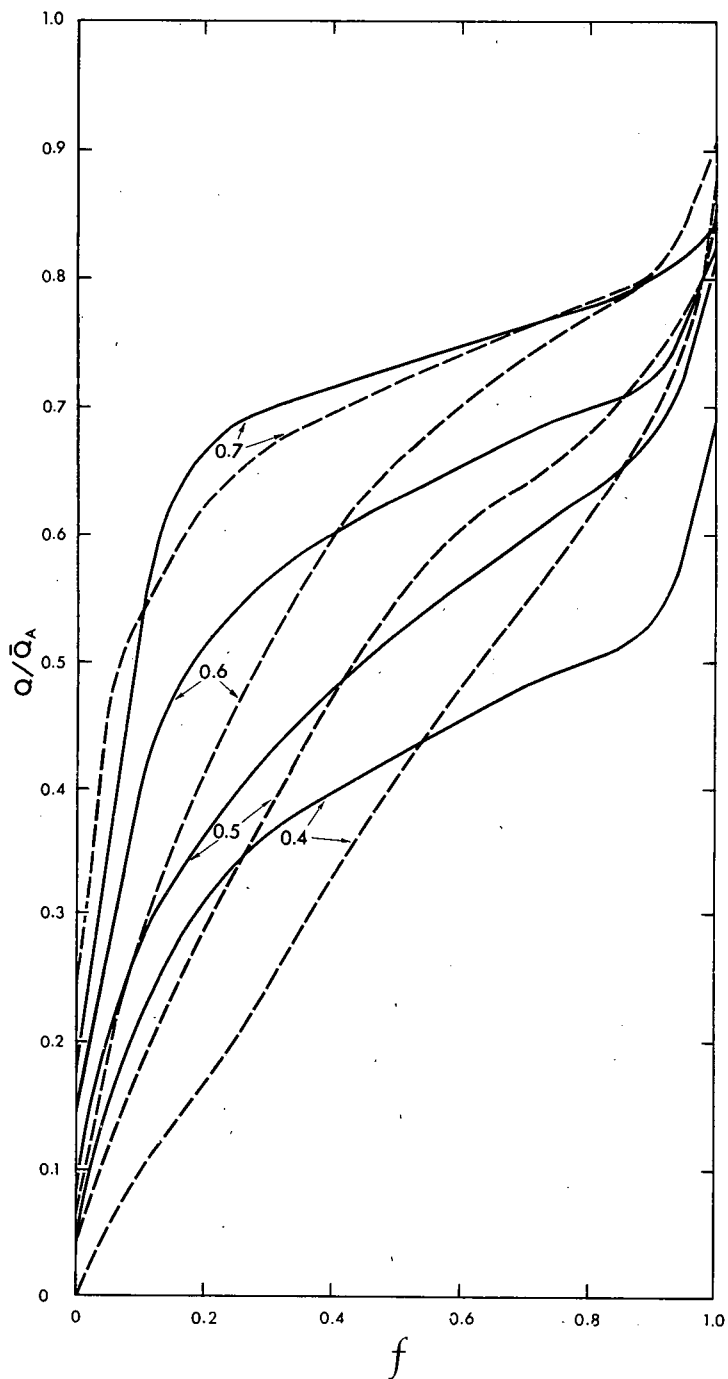


Fig. 4 Generalized cumulative frequency distribution curves for four values of \bar{Q}/\bar{Q}_A . Solid curves obtained in this study. Broken curves derived from Liu and Jordan (1960).

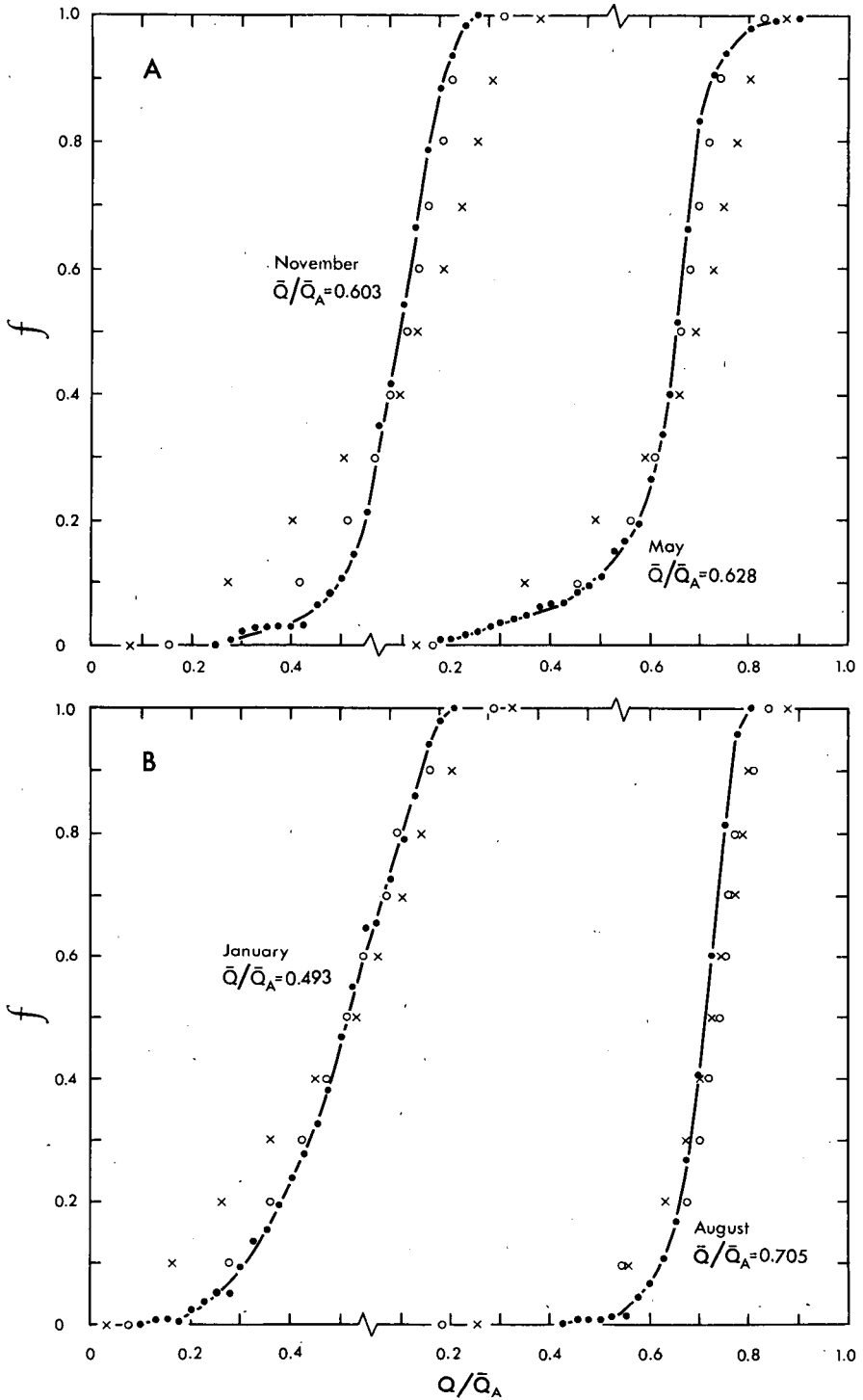


Fig. 5 Comparison of observed cumulative frequency distributions (curves) for May and November at Katherine Research Station (A) and for January and August at Coastal Plains Research Station (B) with distributions predicted from Fig. 3 (open circles) and from Liu and Jordan's (1960) results (crosses).

and August at CPRS had \bar{Q}/\bar{Q}_A ratios of 0.493 and 0.705. Cumulative frequency distributions were calculated for these four months as for the 20 months used for the generalized f-curves. In Fig. 5A the calculated frequencies for May and November at KNRS have been plotted and curves of best fit drawn through these points. Similarly, in Fig. 5B cumulative frequency distribution curves have been drawn through the observed frequencies for January and August at CPRS. For all four months Q/\bar{Q}_A was also obtained for $f=0, 0.1, 0.2, \dots, 1.0$ from the curves presented in Fig. 3 for the calculated values of \bar{Q}/\bar{Q}_A . These sets of predicted frequencies have been plotted in Figs. 5A and 5B as well. It can be seen that agreement between observed and predicted frequencies is extremely good for January at CPRS and May at KNRS, good for November at KNRS and reasonable for August at CPRS. By interpolation Q/\bar{Q}_A values were also obtained for all four \bar{Q}/\bar{Q}_A ratios from Liu and Jordan's generalized curves for $f=0, 0.1, 0.2, \dots, 1.0$. These values have also been included in Figs. 5A and 5B. Note the great improvement in prediction when using the generalized curves obtained from the Australian stations, especially for $\bar{Q}/\bar{Q}_A = 0.493, 0.603$ and 0.628 . As pointed out above, the frequency curves for $\bar{Q}/\bar{Q}_A = 0.7$ obtained by Liu and Jordan and in this study (Fig. 4) are rather similar, resulting in very little improvement for $\bar{Q}/\bar{Q}_A = 0.703$.

In an analysis of the first three years of records for all stations of the Robitzsch actinograph network except Rabaul (where recordings started in 1956), Loewe (1956) presents tables containing monthly frequency distributions of global radiation over 17 equal classes of 50 ly/day for 0 to 850 ly/day. This information has been used here for comparing the observed statistical distributions of global radiation for Darwin, Alice Springs and Melbourne for June and December with the predicted distributions using Fig. 3. The number of occasions on which global radiation was less than or equal to the upper limit of each class (Q_{\max}) was calculated and could be translated into the relative frequency f of Q/\bar{Q}_A , being smaller than or equal to a specific value for each class (Q_{\max}/\bar{Q}_A). Extra-terrestrial radiation values were obtained from Fig. 1. Predicted frequency distribution curves and observed frequencies for all 6 months are presented in Fig. 6 and it can be seen that agreement is good in all cases.

It should be noted, however, that less than 100 daily totals were used by Loewe for calculating the frequency distribution, whereas his total number of classes (especially for the three June months) is comparatively small.

It may be concluded from the development of the present method and the above comparisons, that the statistical distribution of daily global radiation for various latitudes in Australia and Territories can, for many purposes, be predicted sufficiently accurately from reliable monthly averages of daily global radiation. If past records for calculating monthly averages are not available, other methods may have to be used which are admittedly less accurate. It should be remembered that small errors in \bar{Q} result in more significant errors in Q , at constant \bar{Q}_A and f . Except for interpolation methods, several semi-empirical formulae exist, relating global radiation to more readily available meteorological elements and variables such as cloudiness or relative duration of bright sunshine. Certain formulae, developed for whole regions, resulted in global radiation maps (Bureau of Meteorology, 1964; Mani *et al.*, 1967). Other formulae have been modified to suit local requirements (Fitzpatrick and Stern, 1965).

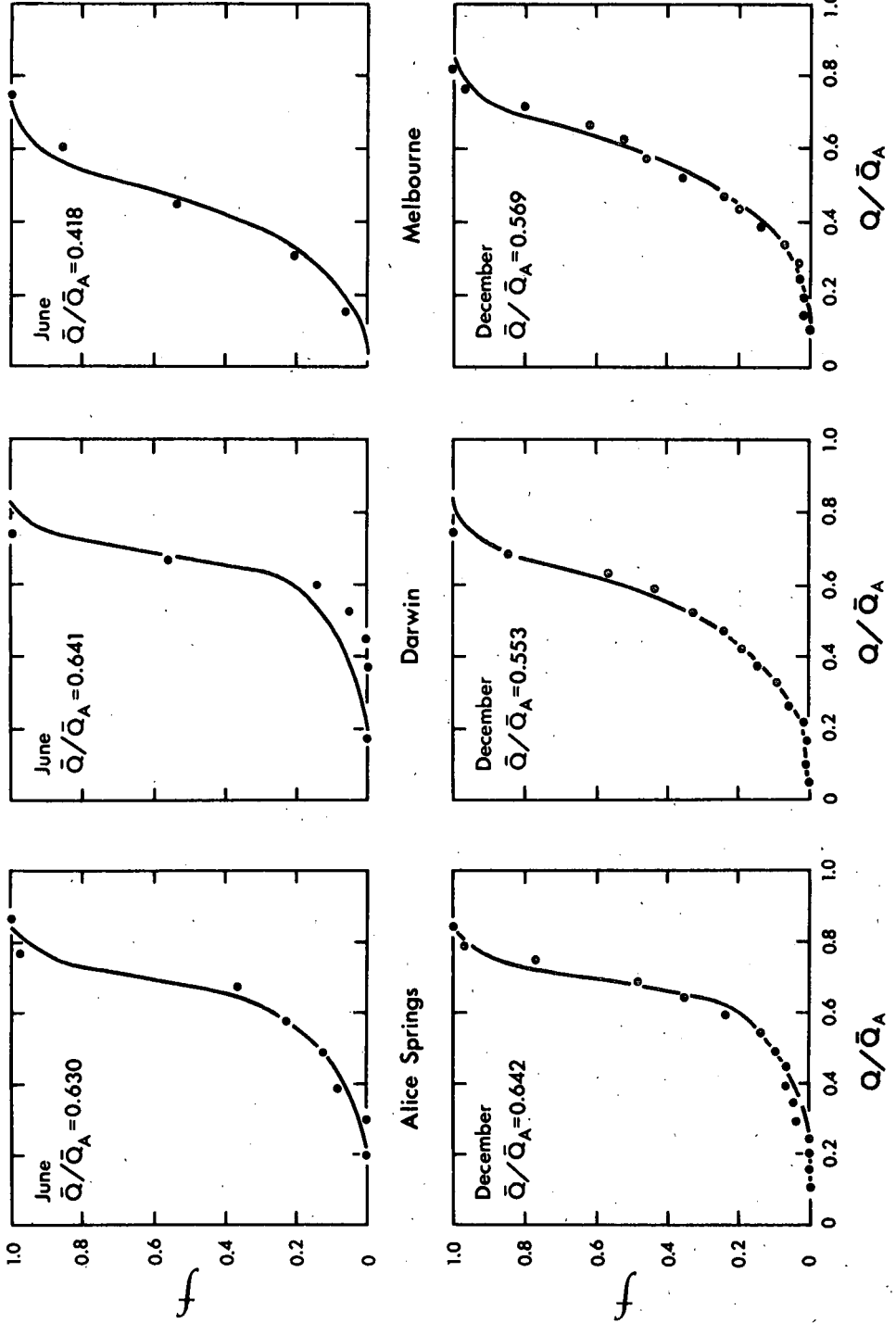


Fig. 6 Comparison of observed and predicted cumulative frequency distributions for June and December at Darwin, Alice Springs, and Melbourne. Solid curves are predicted distributions. Points are calculated frequencies, taken from Loewe (1960).

ACKNOWLEDGMENTS

The assistance of Mrs. A. Komarowski in data extraction and of Mrs. K. Haszler in data processing is gratefully acknowledged.

REFERENCES

- | | | |
|---|------|---|
| Albrecht, F. H. W. | 1956 | Arid Zone Research XI. Proceedings of the Canberra Symposium, pp. 99-105. |
| Bridgman, H. A. | 1969 | Arch. Meteorol., Geophys. Bioklimatol., Ser. B., Vol. 17, pp. 325-344. |
| Bureau of Meteorology | 1964 | Maps of average monthly total radiation in Australia. 12 sheets. Melbourne. |
| | 1966 | Australian Radiation Records, 1962-1964, 25 pp. |
| | 1970 | Solar Radiation Data, Australia, 1965-1968, 31 pp. |
| Fitzpatrick, E. A. and Stern, W. R. | 1965 | J. Appl. Met., Vol. 4, pp. 649-660. |
| Hounam, C. E. | 1963 | Aust. Met. Mag., No. 43, pp. 1-14. |
| | 1969 | Aust. Met. Mag., Vol. 17, pp. 91-94. |
| Jesson, E. E. | 1970 | Int. Solar Energy Soc. Conf., Melbourne, Paper No. 3/5, 6 pp. |
| Liu, B. Y. H. and Jordan, R. C. | 1960 | Solar Energy, Vol. 4, pp. 1-19. |
| Loewe, F. | 1956 | Aust. Met. Mag., No. 15, pp. 31-40. |
| Mani, A., Chacko, O., Krishnamurthy, V. and Desikan, V. | 1967 | Arch. Meteorol., Geophys. Bioklimatol., Ser. B., Vol. 15, pp. 82-98. |
| McCullough, E. C. | 1968 | Arch. Meteorol., Geophys. Bioklimatol., Ser. B., Vol. 16, pp. 129-143. |
| Sellers, W. D. | 1965 | Physical Climatology, University of Chicago Press, Chicago/London. |