551.521.31(94)

ESTIMATES OF SOLAR RADIATION OVER AUSTRALIA

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(Manuscript received May 1963)

Abstract: Some of the equations developed for the estimation of solar radiation are discussed and a set is developed for Australia based on the network of Robitzsch actinometers. Using all data the regression equation $Q/Q_A = 0.26 + 0.50\ n/N$ is obtained and this is applied to Australian sunshine and cloudiness observations to form the basis for maps showing the January and July radiation. Out-going radiation is estimated by the Brunt type equation and net radiation is obtained assuming a universal albedo of 0.23. The chief feature of the distribution of net radiation in January is the relatively small variation across the Continent.

Monthly means of the absorption coefficient are calculated, using Beer's Law, for selected radiation stations.

1. INTRODUCTION

A network of Robitzsch actinometers has been operating in Australia since 1953 but the coverage is inadequate for the preparation of climatological maps of radiation on a continental basis.

It has therefore been necessary to resort to estimation from sunshine or cloudiness and various techniques have been developed for this purpose. Work of particular interest in Australia has been carried out by Black, Bonython and Prescott (1954) and by Bonython, Collins and Prescott (1955).

Since its inception, the Robitzsch actinograph has been the subject of some criticism but the actual instrumental deficiencies or inaccuracy are not referred to here. However, the estimates obtained should be regarded as interim, pending the availability of data from the projected network of more reliable equipment. The Bureau of Meteorology proposes to commence installation within two years, of a network based on the Moll-Gorczynski instrument.

2. ESTIMATION BY ÅNGSTROM TYPE EQUATION

Ångstrom (1924) developed the equation

$$Q = Q_o (a' + b'\ n/N) \qquad \ldots (1)$$

where Q = total radiation received at earth's surface,

Q_o = total radiation received on a cloudless day at surface,

n = actual duration of sunshine,

N = maximum possible duration of sunshine,

a' = constant (= ratio Q/Q_o on overcast day),

b' = constant (= $1 - a'$, since $Q = Q_o$ on a cloudless day).

Data for overcast days at Stockholm gave a value of $a' = 0.25$, from which $b' = 0.75$.

Fritz and McDonald (1949) obtained the relation

$$Q/Q_o = 0.35 + 0.61\, n/N,$$

based on long term data for the United States.

Mateer (1955), using Canadian data for the summer months only, obtained

$$Q/Q_o = 0.35 + 0.68\, n/N,$$

which allows for the fact that the Campbell-Stokes sunshine recorder does not record when the sun is close to the horizon.

This approach was used on Australian data (Hounam 1956) and the following relationship was found

$$Q/Q_o = 0.34 + 0.66\, n/N \qquad \ldots(2)$$

Fig. 1 shows the distribution of the data.

The chief difficulty in the application of this type of equation is obtaining representative values of Q_o. This quantity is known reliably only for stations at which measurements are made and, in extending the geographical area of application using observed or estimated values of n/N, it is assumed that there is no spatial variation in atmospheric turbidity.

3. ESTIMATION FROM RADIATION AT TOP OF ATMOSPHERE

Several workers have modified the Ångstrom equation by replacing Q_o by Q_A, which is the radiation received on a horizontal surface at the top of the atmosphere or which would be received at the surface if there were no atmospheric influence. This considerably simplifies estimation because values of Q_A are readily available (e. g. Smithsonian Tables).

In the equation

$$Q/Q_A = a + b\, n/N \qquad \ldots(3)$$

the "constants" a and b will have different values from a' and b', and results obtained by many workers are listed by Black, Bonython and Prescott (1954). Generally 'a' ranges between 0.15 and 0.30 and 'b' between 0.50 and 0.55.

Thus on an overcast day, $a = Q/Q_A$ would be expected to be less than Q/Q_o, since Q_o is a smaller quantity than Q_A because of atmospheric absorption and reflection due to water vapour, dust and other foreign material.

Glover and McCulloch (1958) obtained $a = 0.27$ and $b = 0.54$ for Kabete, a relatively dry station at approximately 6,000 ft elevation in Kenya.

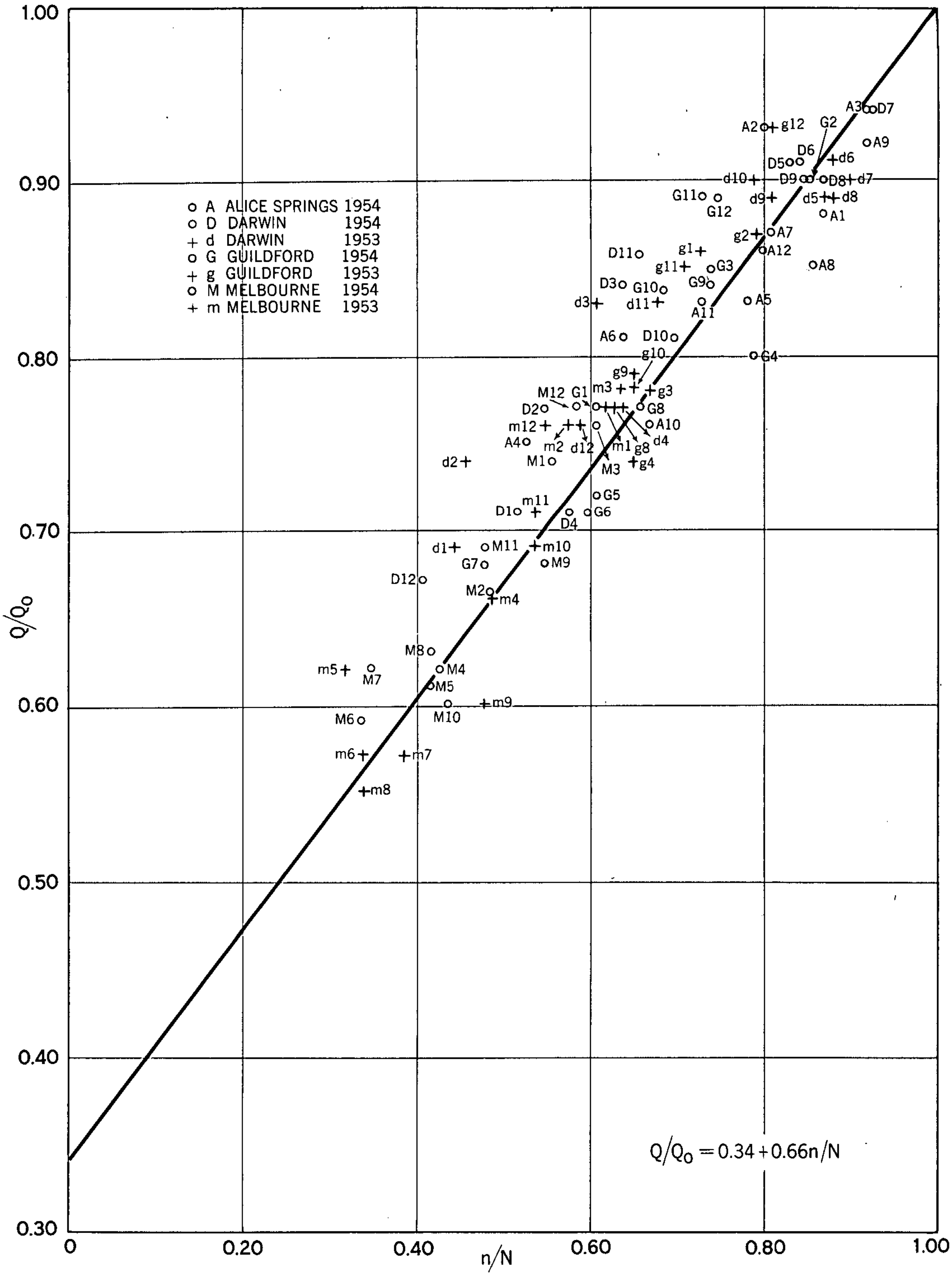

Fig. 1 Relationship between monthly values of Q/Q_0 and n/N for stations in Australian Radiation Network for years 1953 and 1954. Numerals next to letters refer to month of the year, e.g., 1= January; 2=February, etc.

A study by Day (1961) of data for the United Kingdom led to values of 'a' between 0. 10 and 0. 20 and 'b' between 0. 50 and 0. 75. He used these on a regional basis with the dense U. K. sunshine network to estimate monthly radiation over the British Isles.

4. APPLICATION TO AUSTRALIAN RADIATION OBSERVATIONS

Regression analyses were carried out on the monthly mean values for each radiation station, and computed values of monthly and annual coefficients for each station and for the combined 6 stations are shown in Table 1. The variations from month to month for each station and for each month between stations are rather large because of the small sample sizes. The maximum number is only 10 years (Darwin) and for several months at three other stations only 4 years were available.

Taking the 12 months together gives sample sizes ranging between 50 and 100 and, with the exception of Guildford, the coefficients now show only small differences, i. e. 'a' ranges from . 24 to . 30 and 'b' from . 42 to . 52.

Taking each month for the 6 stations as a separate sample gives 30 to 40 items and, with the exception of October and December, there is again good agreement between various monthly values of coefficients, i. e. 'a' ranges from . 20 to . 30 and 'b' from . 46 to . 53.

The total of 458 observations from 6 stations for 12 months gives Eq. (4) which is used later in this paper for estimating radiation over Australia.

$$Q/Q_A = 0.26 + 0.50 \; n/N \qquad \ldots (4)$$

In view of the good agreement between computed coefficients, both between stations using data for all months and between months using data for all stations, the general application of Eq. (4) seems to be justified. This is certainly so until such time as long series of observations are available for a considerably greater number of radiation stations than exist at present.

Table 1. Monthly values of linear regression coefficients 'a' and 'b' in equation $Q/Q_A = a + b \; n/N$.
s = No. of months in sample.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Melbourne	a(	.39	.48	.22	.01	.24	.50	.25	.42	.29	.54	.45	.39	.27
	b(	.29	.14	.52	.94	.51	-.07	.47	.18	.45	-.01	.07	.24	.46
	s(	6	6	6	6	6	6	4	4	5	5	5	4	63
Williamtown	a(	.31	.31	.40	.31	.56	.16	.60	.26	-.22	.46	.40	.30	.30
	b(	.42	.36	.27	.33	.01	.65	.08	.45	1.28	.15	.28	.38	.42
	s(	5	5	5	5	5	4	3	4	4	5	5	4	54
Garbutt	a(	.53	.10	.27	.50	.32	.42	.18	.38	.41	.39	.29	.15	.24
	b(	.02	.73	.44	.12	.40	.36	.62	.38	.36	.31	.45	.59	.52
	s(	4	4	5	4	5	5	4	4	4	4	5	3	51
Alice Springs	a(	.26	-.18	.39	.35	.41	.24	.20	-.05	.56	.29	.18	.02	.26
	b(	.46	.85	.34	.40	.30	.59	.63	.86	.19	.48	.61	.80	.51
	s(	8	8	8	9	9	9	8	8	7	6	6	6	92
Guildford	a(	.03	.39	.25	.46	.33	.33	.32	.37	.41	.58	.32	.17	.36
	b(	.81	.31	.47	.17	.40	.43	.46	.37	.30	.06	.45	.69	.38
	s(	7	7	8	8	7	7	8	8	8	7	7	7	89
Darwin	a(	.34	.39	.19	.14	.23	.20	.45	.72	.36	.67	.52	.23	.24
	b(	.26	.20	.60	.60	.51	.58	.27	-.02	.37	-.09	.05	.50	.50
	s(	9	10	10	10	10	10	9	9	9	8	8	7	109
Values based on 6 stations.	a(	.27	.27	.25	.20	.27	.29	.28	.30	.26	.40	.25	.19	.26
	b(	.47	.47	.49	.53	.47	.50	.50	.46	.52	.29	.51	.60	.50
	s(	39	40	42	42	42	41	36	37	37	35	36	31	458

5. ESTIMATION OF SOLAR RADIATION FOR JANUARY AND JULY

Equation (4) was applied to estimate mean solar radiation for the months of January and July. Mean monthly values of Q_A were obtained from the Smithsonian Tables (1951). Values of n/N for the climatological network were estimated from a regression equation based on cloudiness and sunshine observations at Australian stations equipped with Campbell-Stokes sunshine recorders.

Figs. 2 and 3 show the distribution of total short wave radiation for January and July estimated by the above procedure.

Areas of maximum radiation in January in excess of 650 cal cm^{-2} day^{-1} occur over the western half of New South Wales and over an area of West Australia extending from West Gascoyne to the northern wheatbelt. Totals along the far south and east coasts are mainly just under 550. The lowest values occur over the monsoonal north, being less than 450 cal cm^{-2} day^{-1} over northern Arnhem Land and the north of Cape York Peninsula.

Because of the relatively small differences in Q_A in January over Australia, the distribution of estimated radiation follows very closely that of the sunshine ratio n/N.

The average distribution in July, based on the same equation, is shown in Fig. 3. Because of the large latitudinal differences in Q_A in this month, isopleths of Q follow latitudes more closely than in January, ranging between less than 200 cal cm^{-2} day^{-1} in the far south and over 400 over most of the tropical north.

6. ESTIMATION OF OUTGOING RADIATION

Outgoing radiation was obtained from the empirical equation (Brunt 1939)

$$Qb = 1440\,\sigma Ta^4\ (0.47 - 0.067\sqrt{e_d})\ (0.1 + 0.9\ n/N)$$

where Qb is the outgoing or back radiation in cal cm^{-2} day^{-1},

e_d the mean surface vapour pressure (mb),

Ta is mean air temperature in ^{o}K,

σ is the Stefan constant.

Figs. 4 and 5 show the estimated distribution of outgoing radiation for January and July using the above equation.

Outgoing radiation in January is a maximum over the sub-tropical arid zone extending from northwest New South Wales to the Murchison district of West Australia, i.e. centred on about latitude 28°S. The absolute maximum shown near the coast in West Australia results from the combination of high temperature and low cloudiness. Losses are very small in the monsoonal rainfall zone of Northern Australia.

In July (Fig. 5) the estimated values are a maximum over the inland tropical arid zone where temperatures are relatively high and cloudiness is very small. In coastal areas of the tropical north, although temperatures are higher, radiation losses are reduced by greater cloudiness and vapour pressure. In the south losses are less because of lower temperatures and greater cloudiness.

7. ESTIMATION OF NET RADIATION

The various measurements of albedo in different countries indicate the wide variation possible with this factor.

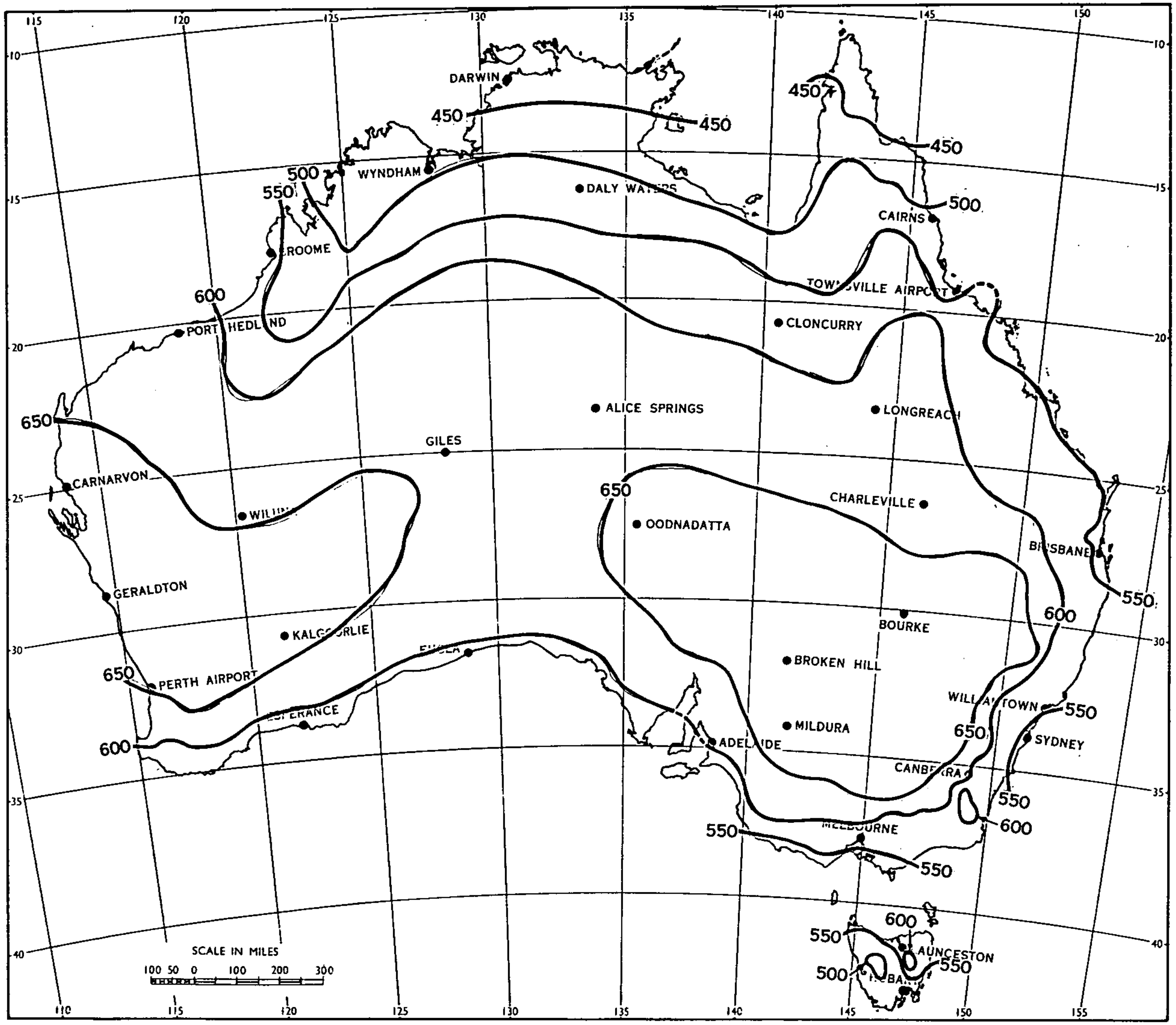

Fig. 2 Average distribution of total radiation in Cal cm^{-2} day^{-1} in January, estimated from $Q/Q_A = 0.26 + 0.50n/N$

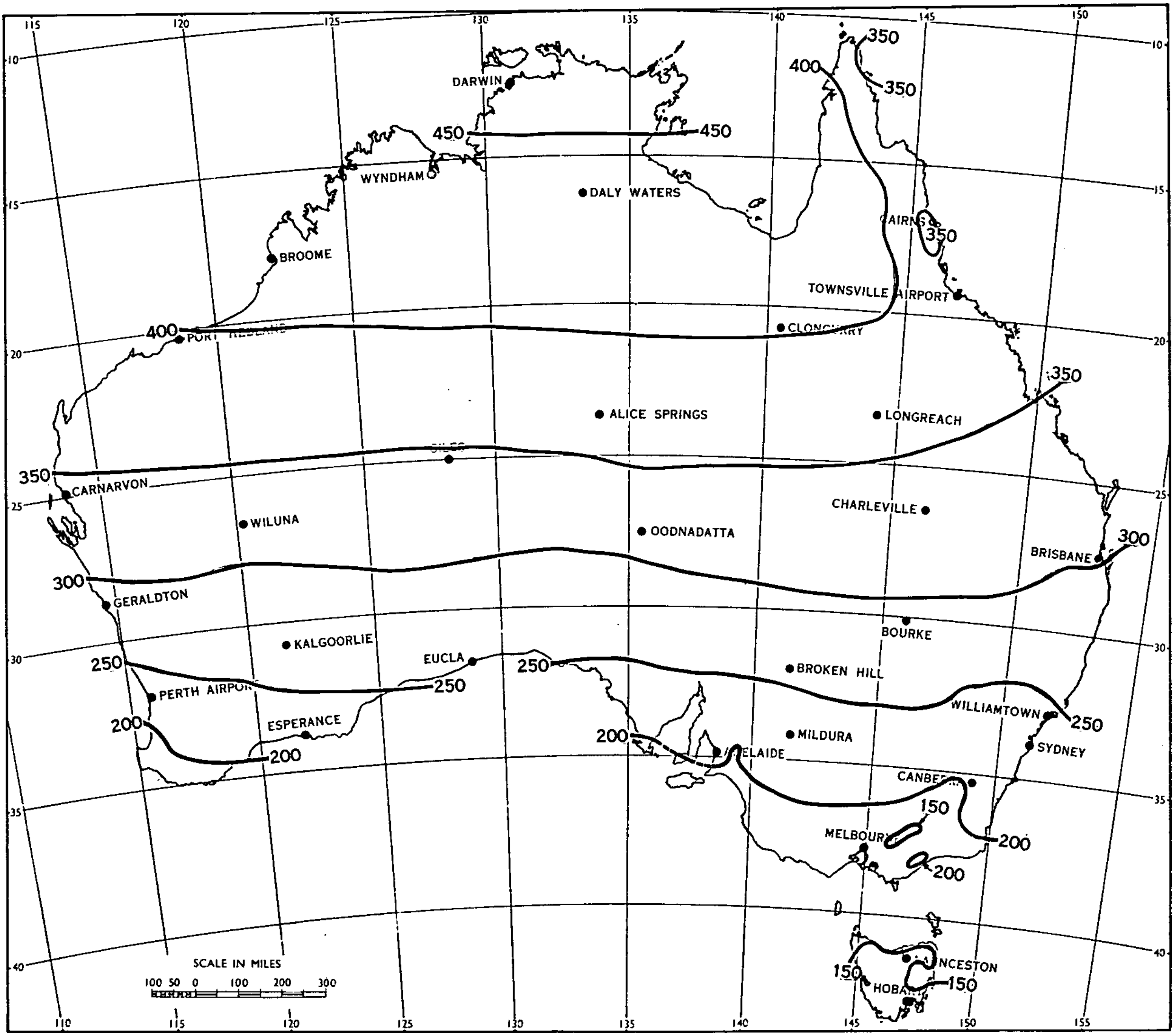

Fig. 3 Average distribution of total radiation in Cal $cm^{-2}\,day^{-1}$ in July, estimated from $Q/Q_A = 0.26 + 0.50\,n/N$

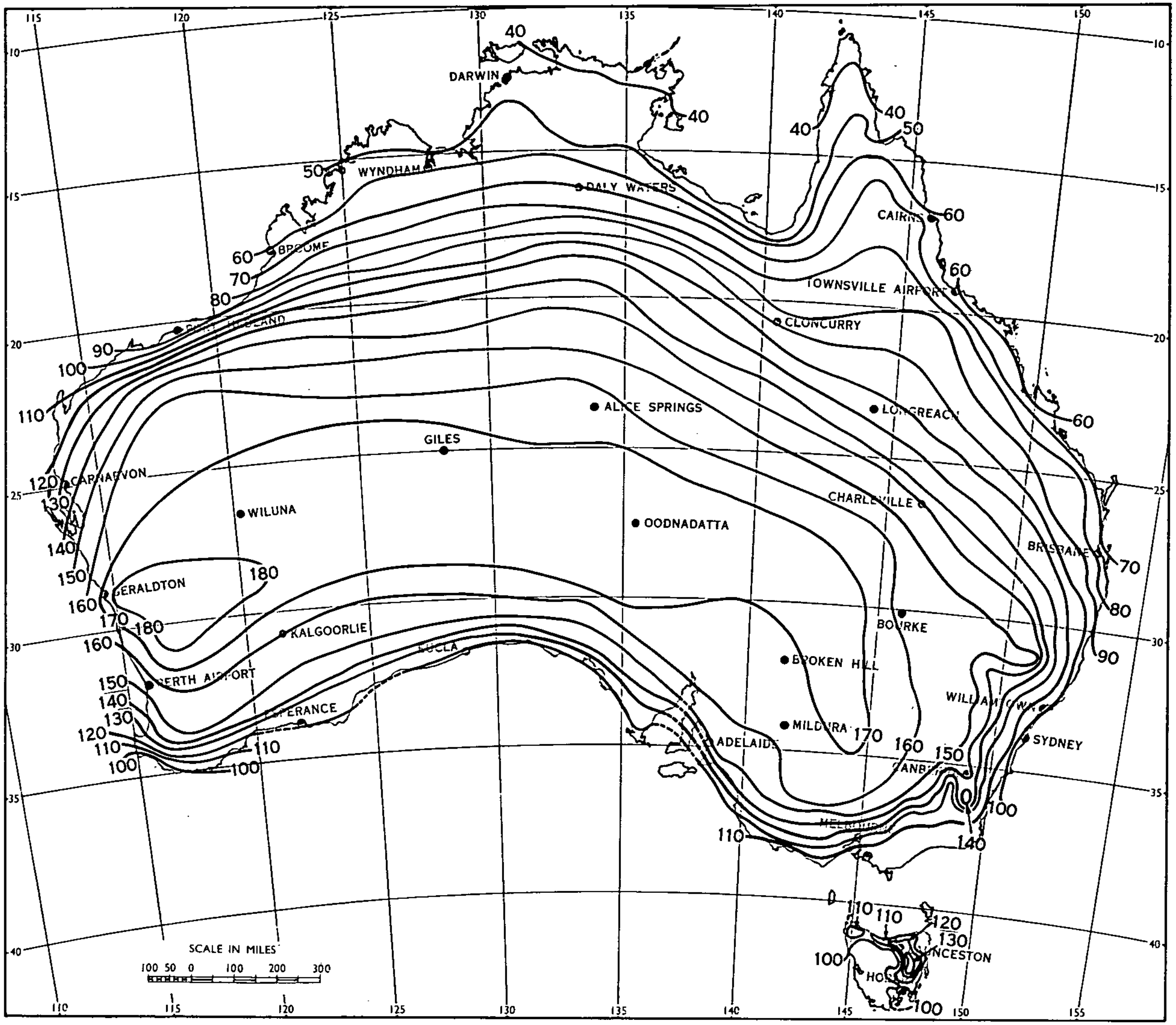

Fig. 4 Estimated outgoing radiation in Cal. cm^{-2} day^{-1} in January, based on $Q_b = 1440\sigma T_a^4 (0.47 - 0.067\sqrt{e_d})(0.1 + 0.9n/N)$

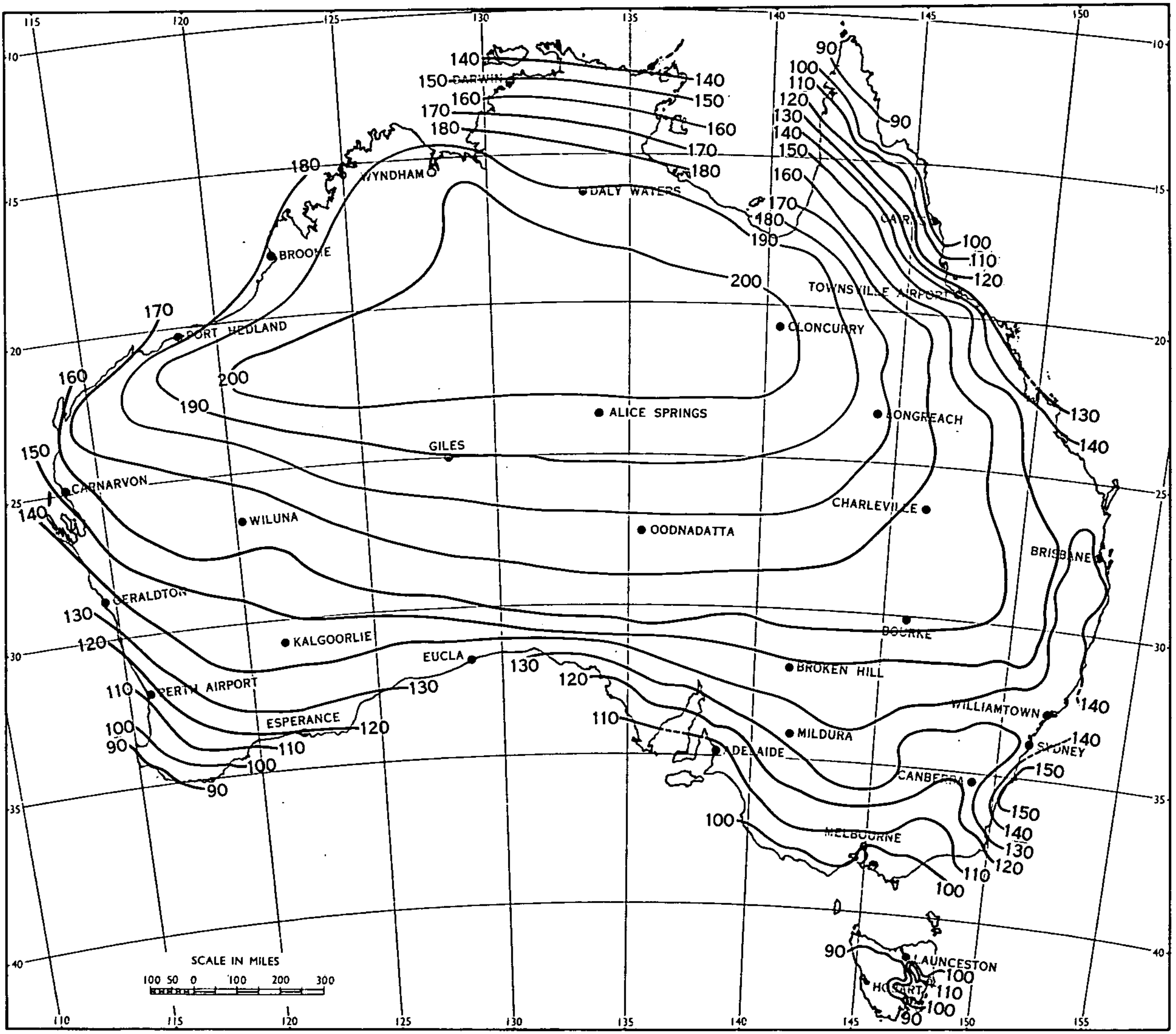

Fig. 5 Estimated outgoing radiation in Cal cm^{-2} day^{-1} in July, based on $Q_b = 1440\sigma T_a^4(0.47 - 0.067\sqrt{e_d})(0.1 + 0.9n/N)$

The matter is simplified somewhat if we ignore water surfaces, which have a relatively low albedo of 0.06 to 0.07, and snow surfaces whose albedo can be assumed to be over 0.4. This leaves vegetated and unvegetated land surface to consider.

Ångstrom (1962) quotes albedo for sand and rocks free from vegetation in the range 0.15 and 0.30; woods, grass fields and land covered by other forms of vegetation 0.05 to 0.15. However, de Vries (1959) reporting on investigations carried out at Deniliquin quotes albedo of 0.23 as an average value for both dry land and irrigated pastures.

Monteith (1959) quotes measurements by Budyko in Russia in the range 0.15 to 0.25 for pastures and growing crops, and by Thornthwaite approximately to 0.26 for vegetables. Monteith has found values of 0.25 to 0.27 for grass and vegetables at Rothamsted, whilst Aslyng and Nielsen (1960) have measured values of 0.15 to 0.23 over green grass.

A mean albedo of 0.23 has been selected for use in the estimation of net radiation over the Australian land surface, based mainly on the value found by de Vries at Deniliquin for dry land and irrigated pastures.

Net radiation was then computed for January and July from 0.77 x (incoming radiation) minus (outgoing radiation) and the distribution is shown in Figs. 6 and 7. An interesting feature in January (Fig. 6) is the relatively small range across Australia. Minimum value is just under 300 cal cm^{-2} day^{-1} over northern Arnhem Land, most of Tasmania and the southern fringe of Victoria and far southwest coast of West Australia. The maximum barely exceeds 350 over the northern wheat belt of New South Wales.

In July (Fig. 7) there is a steady latitudinal decrease from 200 cal cm^{-2} day^{-1} in the extreme north to less than 50 over most of the area south of 32°S lat. Estimates for Tasmania are close to zero.

8. ATMOSPHERIC ABSORPTION

The depletion of the solar beam is given by Beer's Law,

$$Q = Q_A \; q^m \qquad \ldots (5)$$

integrated for all wave lengths, where q is the transmission coefficient (related to the absorption coefficient k by $q = e^{-k}$) and m is the optical (air mass) path.

Thus it would be expected that equations of the type described in Section 3 involving Q_A would incorporate errors due to the climatological variation in q, i.e. the spatial and temporal variations in q which depend on variations in the dust and water content in both the horizontal and vertical.

Table 2 gives an indication of the magnitude of q^m for days without cloud, i.e. absorption and reflective losses due to dust and water vapour only. Values tabulated are the ratio Q_o/Q_A where Q_o is the mean value based on a few cloudless days.

Table 2. Values of the ratio Q_o/Q_A.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Melbourne	.76	.77	.77	.76	.71	.71	.78	.79	.80	.80	.78	.78
Alice Springs	.78	.80	.80	.79	.79	.77	.80	.82	.80	.80	.79	.78
Guildford	.77	.79	.80	.81	.77	.74	.74	.77	.79	.79	.79	.79
Darwin	.72	.70	.69	.71	.73	.73	.75	.76	.74	.73	.72	.72

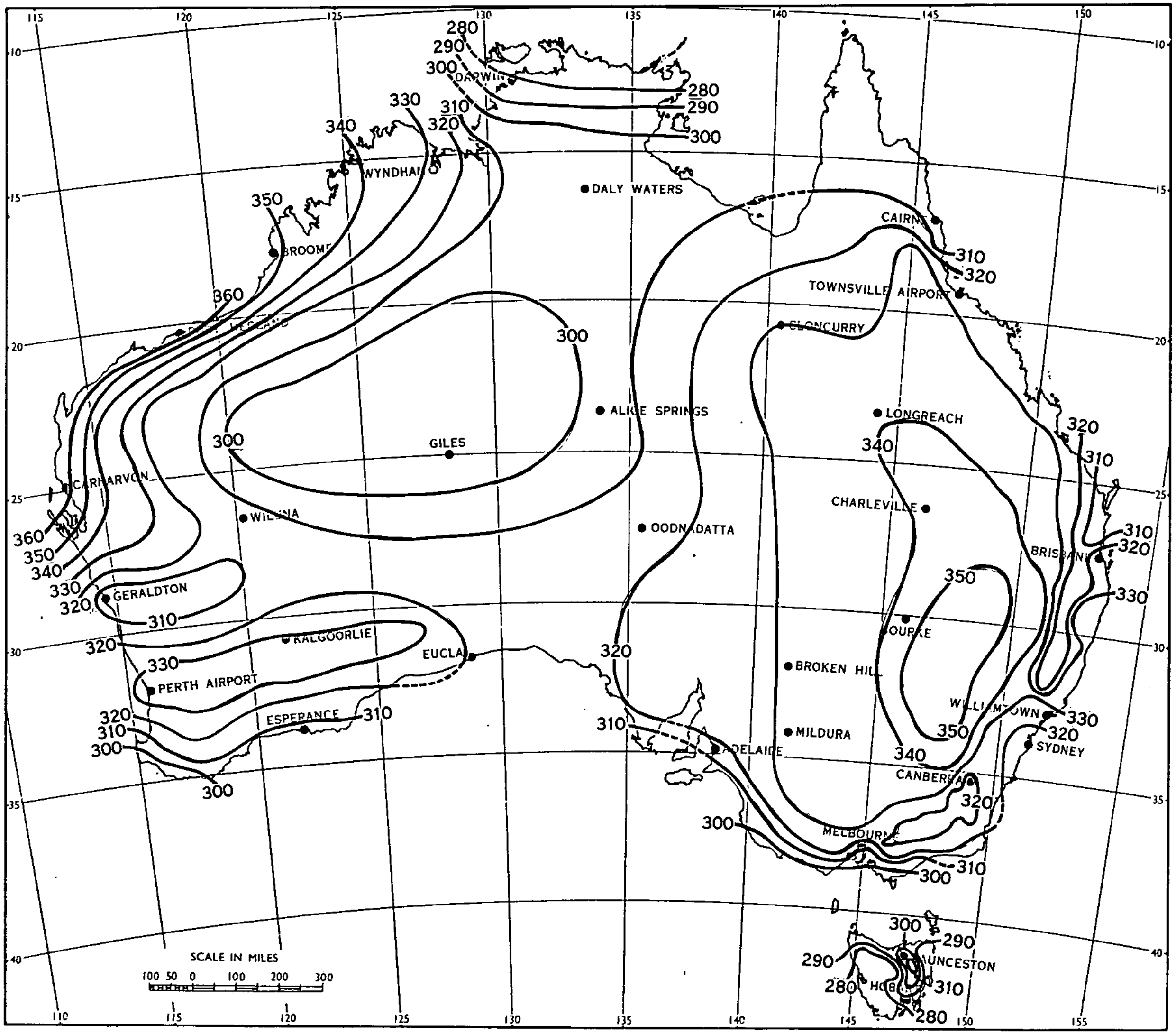

Fig. 6 Estimated net radiation Cal cm^{-2} day^{-1} in January assuming uniform albedo of 0.23

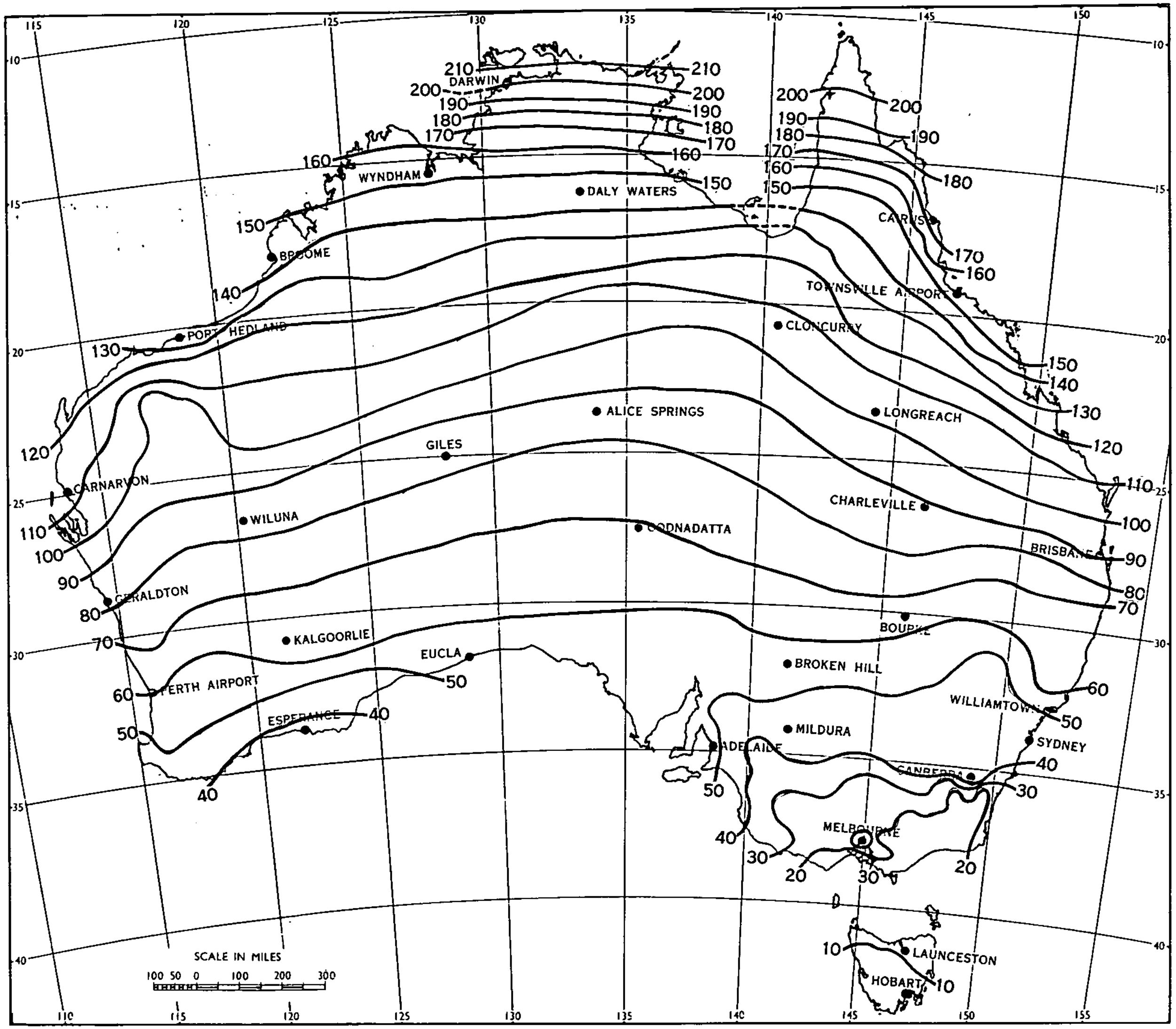

Fig. 7 Estimated net radiation Cal $cm^{-2} day^{-1}$ in July assuming uniform albedo of 0.23

Consider now the two related equations (1) and (3) discussed above,

$$Q/Q_o = a' + b' \; n/N$$

$$Q/Q_A = a + b \; n/N.$$

For the same set of data

$$Q_o/Q_A = \frac{a + b \; n/N}{a' + b' \; n/N}.$$

Putting $n/N = 1$ for cloudless conditions and since $a' + b' = 1$,

$$Q_o/Q_A = a + b. \qquad \ldots (6)$$

Equation (4) gives values of $a = 0.26$ and $b = 0.50$, and substituting these in equation (6) gives

$$Q_o/Q_A = 0.76$$

which agrees fairly closely with measured values shown in Table 2.

Values of q calculated from equation (5) are shown in Table 3.

Table 3. Monthly values of transmission coefficient q.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Melbourne	0.91	0.91	0.91	0.93	0.91	0.93	0.95	0.93	0.93	0.93	0.91	0.91
Alice Springs	0.91	0.91	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.91	0.91
Guildford	0.91	0.91	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.91	0.91
Darwin	0.87	0.87	0.87	0.89	0.91	0.91	0.91	0.91	0.89	0.89	0.89	0.89

All stations listed in Table 3 exhibit maximum values of q in the winter months and minima in summer. From plotted data (not reproduced here) a high negative correlation between q and (surface) vapour pressure was evident.

9. SUMMARY

(i) Regression equations have been developed for each month for each radiation station and for the group of 6 stations. An integrated equation is also derived for all stations based on all records.

(ii) The regression equation based on all records, all radiation stations, is used to compute incoming radiation for January and July over Australia.

(iii) Outgoing (back) radiation is estimated from the Stefan type (σT^4) equation. Applying an albedo of 0.23 to the incoming radiation, the net radiation is then estimated.

(iv) Transmission coefficients are computed for selected stations and values indicate that atmospheric absorption in Australia is relatively small compared with some overseas sites.

10. CONCLUSIONS

(i) The next step should be a study of the radiation observations relative to the radiosonde soundings of water vapour content through the depth of the atmosphere and, if possible, an assessment of the dust content through the vertical. This approach would also require that consideration be given to the elevation of stations as affecting the total water content in the air mass above a station.

(ii) There does not appear to be any advantage in undertaking this more detailed approach until the proposed Australian network of Moll-Gorczynski instruments replaces the existing Robitzsch network.

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