TWO YEARS OF SOLAR RADIATION MEASUREMENTS AT DENILIQUIN

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Abstract: Results of solar radiation measurements at Deniliquin (35° 32' S, 144° 58' E) during the period March 1956 to February 1958 by means of a Moll-Gorczynski solarimeter are presented and analysed.

The daily totals of radiation intensity on a horizontal surface (Q) are correlated with hours of bright sunshine (n, measured with a Campbell-Stokes instrument) and fractional cloudiness (m) by the equations:

$$Q/Q_A = 0.27 + 0.54\, n/N,$$

$$Q/Q_A = 0.83 - 0.45\, m,$$

where Q_A is the calculated intensity on a horizontal surface at the upper limit of the atmosphere and N the maximum possible hours of bright sunshine.

The present results are compared with other radiation measurements in Australia.

1. INTRODUCTION

Recent years have seen a rapidly increasing interest in the solar radiation climate of Australia (Black, Bonython and Prescott 1953; Albrecht 1956; Loewe 1956; Sapsford 1957). As a contribution to this subject results of two years of solar radiation measurements at Deniliquin (N.S.W.) are presented in this paper.

The methods used are described in section II and results are presented in section III. A discussion of these results and a comparison with those of other investigators is given in section IV.

2. METHODS OF MEASUREMENT AND ANALYSIS

The instrumentation and method of analysis were similar to those described by the author in detail for solar radiation measurements at Wageningen, Netherlands (de Vries, 1955).

The intensity of total short wave radiation from sun and sky (the so-called total global radiation) was measured at the C.S.I.R.O. Regional Pastoral Laboratory, Deniliquin, New South Wales, (35° 32' S, 144° 58' E, altitude 102 m) by a Moll-Gorczynski solarimeter, manufactured by Kipp and Zonen, connected through a series resistor to a Cambridge thread recorder. The properties of the instrument were investigated in detail by Bener (1951) and the reader is referred to his paper for a full discussion.

From 1 March 1956 to 14 June 1957 the solarimeter was situated on the roof of the Laboratory at a height of 5.10 m, after the latter date it was transferred to the meteorological enclosure of the Laboratory where it is supported on a pole at a height of 2.20 m.

A calibration of the instrument by the C.S.I.R.O. Division of Meteorological Physics before installation yielded exactly the same value as that given by the manufacturers. No recalibration was carried out during the period reported on here. However, previous experience over many years (de Vries, 1955) has shown that instruments of this type do not change their calibration as long as the black surface and the junctions remain in good condition, as was the case.

Daily sums of total global radiation (Q) were obtained by planimetering the recorded curves. They are expressed as cal cm^{-2} (1 cal cm^{-2} = 4.1855×10^4 J m^{-2}).

Systematic corrections due to a slight dependence of the calibration factor on ambient temperature and radiation intensity, and to the geometry of the recorder (see Bener, 1951; de Vries, 1955) were applied to the daily totals. Average correction factors for each month are listed in Table 1. Random errors in the individual Q-values are estimated at 5 per cent.

Hours of bright sunshine have been measured since January 1951 with a Campbell-Stokes recorder at the C.S.I.R.O. Falkiner Memorial Field Station (35° 22' S, 145° 0' E) where a climatological station was established in October 1947 by the Commonwealth Bureau of Meteorology.

Table 1. Average correction factors

January	1.02	July	0.94
February	1.01	August	0.95
March	1.00	September	0.97
April	0.97	October	0.98
May	0.95	November	1.00
June	0.94	December	1.01

Cloudiness was estimated daily at the Laboratory at 9 a.m. and 3 p.m. Australian eastern time. The average of these values was taken as representative for the cloudiness during daylight hours (cf. de Vries, 1955).

Statistical relations between Q and duration of bright sunshine or cloudiness were assumed to be of the form:

$$Q/Q_A = a + bn/N, \quad (1)$$

$$Q/Q_A = a' - b'm, \quad (2)$$

where Q_A is the total radiation intensity on a horizontal surface at the upper limit of the atmosphere (Angot's value, see Brunt, 1952) and N the maximum possible duration of sunshine. Best estimates of the "constants" in these equations were determined by the method of least squares for each month separately and for all observations.

3. RESULTS

Daily values of total global radiation from March 1956 to February 1958 inclusive are given in the appendix. When no radiation records were available (due to faults in the recorder or the transmission) the missing values have been filled in by application of Equation (1) with values of the constants given in Table 2; these Q-values are given in brackets in the appendix.

The best estimates of the constants in Equations (1) and (2) when applied to all pairs of simultaneous observations of Q and n/N or Q and m were found to be:

$$a = 0.27, \ b = 0.54, \ a' = 0.83, \ b' = 0.45.$$

Table 2. Values of Q_A at 35° 32' S

Month	Date	Q_A(cal/cm^2)	Month	Date	Q_A(cal/cm^2)
I	1	1014	VII	1	373
	11	1004		11	375
	21	998		21	392
II	1	990	VIII	1	447
	11	984		11	495
	21	932		21	549
III	1	853	IX	1	610
	11	768		11	671
	21	700		21	725
IV	1	638	X	1	768
	11	583		11	810
	21	530		21	860
V	1	474	XI	1	925
	11	427		11	980
	21	390		21	1010
VI	1	375	XII	1	1020
	11	370		11	1027
	21	371		21	1029

Values of Q_A for the latitude 35° 32' S are listed for each 1st, 11th and 21st day of a month in Table 3. The standard deviations,

$$\sigma = \left[\sum_1 (Q_{mi} - Q_{ci})^2 / Q_A^2 (N - 2)\right]^{\frac{1}{2}} \qquad (3)$$

where Q_{mi} is the measured Q-value and Q_{ci} that calculated from Equations (1) or (2), where σ = 0.089 for Equation (1) and σ = 0.099 for Equation (2)

Values of a, a + b, a' and b' for each month separately are listed in Table 3.

Table 3. Values of the constants in Equations (1) and (2)

Month	a	a + b	a'	b'
I	0.28	0.89	0.88	0.40
II	0.26	0.77	0.77	0.37
III	0.28	0.83	0.86	0.48
IV	0.30	0.81	0.84	0.43
V	0.27	0.79	0.82	0.45
VI	0.26	0.78	0.77	0.46
VII	0.26	0.77	0.85	0.54
VIII	0.31	0.73	0.79	0.41
IX	0.31	0.77	0.81	0.41
X	0.24	0.81	0.87	0.49
XI	0.22	0.79	0.84	0.40
XII	0.28	0.88	0.88	0.45

4. DISCUSSION

The present measurements cover only two years both of which had rather exceptional weather. Average monthly values of n/N for this period are compared with average values for the years 1951 to 1957 in Table 4. It will be noted that the autumn and winter of 1956 had considerably less sunshine than average, whilst the reverse holds true for the same period in 1957.

Average Q-values, calculated from Equation (1) with $a = 0.27$, $b = 0.54$ are also listed in Table 4. Loewe (1956) has published average values (1953-1955) for two coastal stations with somewhat lower latitudes than Deniliquin, viz. Guildford (31.9°S, 116.0° E) and Williamtown (32.8° S, 151.8° E). Deniliquin receives slightly more radiation than Guildford in January and February, but slightly less in the remaining months. In comparison with Williamtown it has higher averages in summer and slightly lower ones in winter, much as one would expect from the differences in latitude and the general climatic conditions in these localities.

Table 4. Average values of Q_A, n/N and Q

	n/N				Q_A	Q
Month	1956	1957	1958	1951-1957	(cal/cm^2)	(cal/cm^2)
I		0.87	0.82	0.78	1002	691
II		0.78	0.72	0.78	956	660
III	0.52	0.79		0.74	738	494
IV	0.54	0.74		0.66	559	352
V	0.56	0.76		0.58	413	240
VI	0.52	0.61		0.49	371	197
VII	0.49	0.53		0.54	390	218
VIII	0.60	0.69		0.62	523	314
IX	0.68	0.70		0.67	694	437
X	0.54	0.74		0.65	838	520
XI	0.74	0.79		0.76	986	670
XII	0.81	0.70		0.77	1024	707

The values found for a and b in Equation (1) agree well with those reported by Black, Bonython and Prescott (1954) for Dry Creek and Mt. Stromlo, viz.

	Lat.	Longt.	a	b	a + b	Period
Dry Creek	34.8	138.6	0.30	0.50	0.80	1947-1950
Deniliquin	35.5	145.0	0.27	0.54	0.81	1956-1958
Mt. Stromlo	35.3	149.1	0.25	0.54	0.79	1928-1939

The values of a + b also fit in well with those obtained for other latitudes (see Glover and McCulloch, 1958).

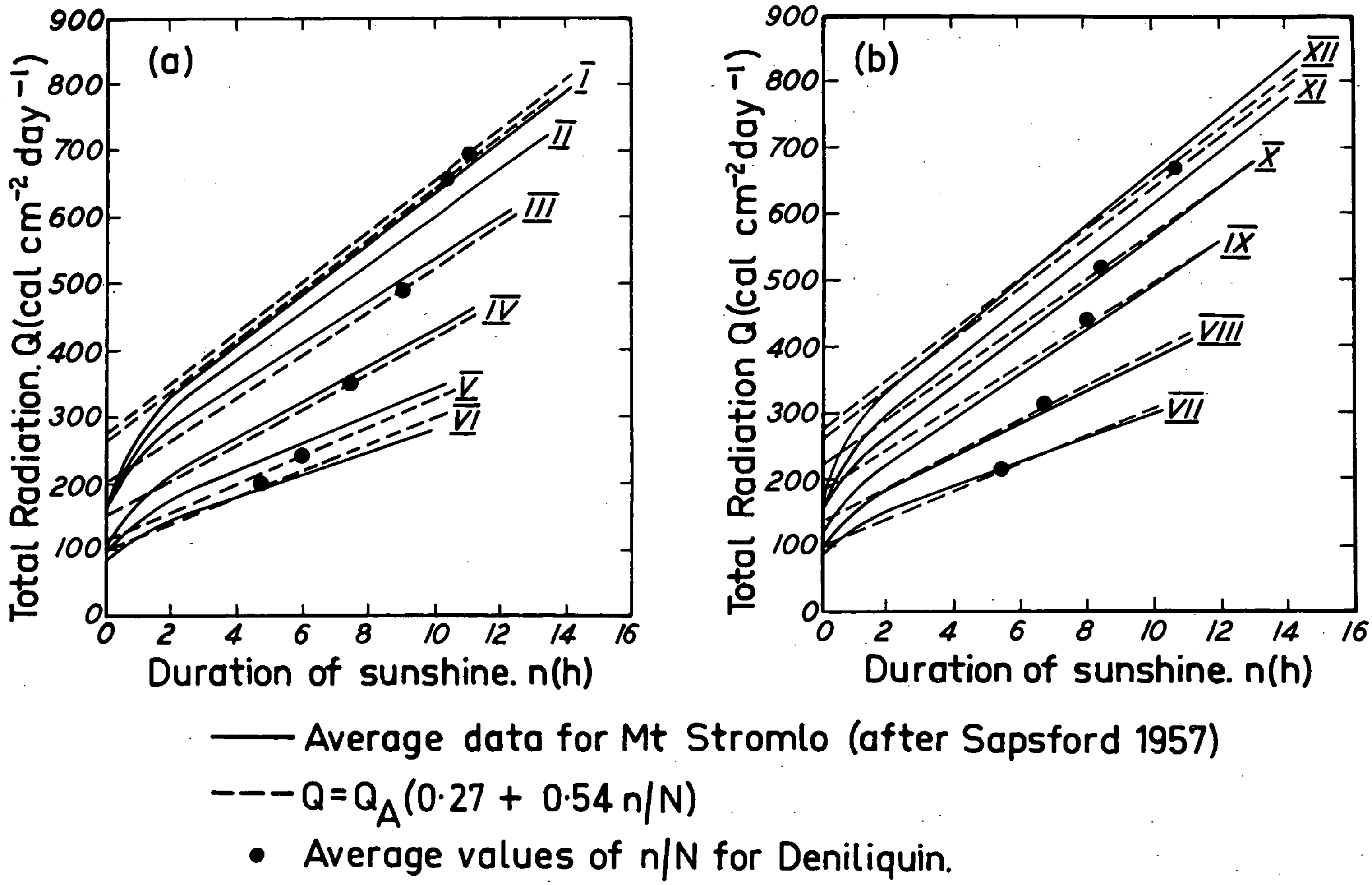

Fig 1. Daily totals of total global radiation (Q) in relation to duration of bright sunshine (n). (a) January to June. (b) July to December.

A more detailed comparison of the values predicted by Equation (1) and the Mt. Stromlo data is given in Fig. 1, which shows the observed average relation between Q and n for each month, as published by Sapsford (1957), together with the lines calculated from Equation (1) with a = 0.27, b = 0.54. The points corresponding to average values of n/N for Deniliquin (Table 4) are indicated by a circle. In the figures the curves are terminated at average values of N for each month. The agreement between the two sets of curves is as close as can be expected allowing for the approximate nature of Equation (1) and possible differences in atmospheric turbidity and cloud density between the two localities. For some months, notably February and November, an even better agreement is obtained by using the monthly a- and b-values of Table 3. For other months, January and December in particular, the agreement becomes less close. It will be noted that the values of Table 3 were obtained from approximately 60 pairs of observations only.

It is remarkable that the values of a + b (and also of a'), which are a measure of the transparency of the atmosphere in the absence of cloud, are smaller in February and November than in the preceding and following months. The Mt. Stromlo data show a similar behaviour. This indicates that in February and November there must be an extra source of turbidity over southeast Australia.

It also follows from Fig. 1 that Equation (1) with a = 0.27, b = 0.54, is not inferior to the method proposed by Sapsford for predicting monthly radiation intensities except at low values of n/N, say $n/N < 0.2$. However, these low values will rarely occur when periods of a month are considered.

Finally Fig. 2 shows a comparison between the relation (2) with a' = 0.83, b' = 0.45 and the quadratic relation derived by Black (1956) for a worldwide network of stations. The differences indicate that for a given value of m the cloud density over Deniliquin is less than the average for the stations used in Black's analysis.

It will be noted that the standard deviation for estimates derived from Equation (2) is only slightly higher than that for estimates from (1), viz. 0.099 against 0.089. These values apply to Q-values for single days; with averages for periods of k days the standard deviations are to be divided by $k^{\frac{1}{2}}$ (Brooks and Carruthers, 1953). This implies that satisfactory estimates of solar radiation intensity can be obtained from visual estimates of fractional cloudiness during daytime. The latter are, of course, more generally available than measurements of sunshine hours.

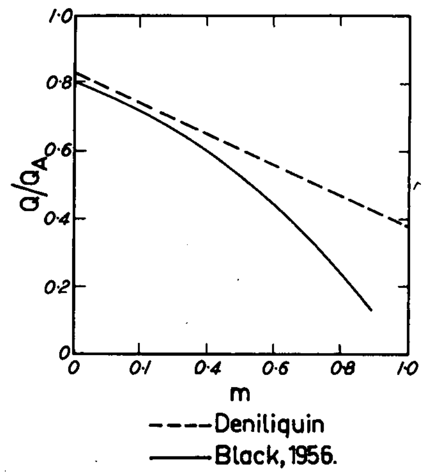

Fig 2. Comparison between $Q/Q_A = 0{\cdot}83 - 0{\cdot}45m$ (Deniliquin) and $Q/Q_A = 0{\cdot}803 - 0{\cdot}340m - 0{\cdot}458m^2$ (Black. 1956)

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Appendix. Daily totals (in cal/cm^2) of total global radiation at Deniliquin

1956/57	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II
1	(529)	309	74	285	199	197	218	345	412	825	875	415
2	(422)	516	80	287	86	359	(440)	522	438	587	518	233
3	423	479	246	244	150	341	476	232	655	778	787	827
4	604	393	324	41	180	369	472	130	557	829	859	748
5	433	382	314	160	131	(314)	499	220	713	831	863	586
6	223	447	370	139	21	329	540	292	739	766	816	381
7	492	479	333	97	175	200	363	514	762	589	886	185
8	542	447	331	102	163	292	(504)	584	743	579	870	726
9	648	387	285	281	277	314	366	377	489	844	771	774
10	(630)	304	162	267	(256)	166	445	540	550	785	856	480
D	495	414	252	190	164	288	432	376	606	741	810	536
11	137	333	73	81	(109)	301	357	408	435	883	839	760
12	231	481	194	174	285	261	529	618	605	420	839	669
13	(233)	440	333	263	322	235	535	653	709	582	685	753
14	(231)	275	317	258	257	208	543	548	804	872	859	740
15	581	352	232	257	220	346	539	145	311	849	835	335
16	413	319	125	239	(102)	(286)	543	355	438	816	855	740
17	504	300	176	195	126	(269)	342	269	459	407	798	727
18	237	276	164	266	(115)	266	286	322	510	663	732	699
19	(546)	157	297	166	293	334	288	238	666	839	530	713
20	(254)	251	299	312	308	325	285	453	693	879	663	592
D	337	318	221	221	214	283	425	401	563	721	764	673

Appendix (Contd.)

1956/57	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II
21	(329)	300	181	269	286	277	385	640	716	872	696	721
22	304	182	108	141	254	252	404	675	702	885	844	703
23	332	241	114	261	(196)	364	482	600	734	852	777	626
24	506	262	226	40	261	234	551	455	283	842	822	718
25	507	114	144	171	255	306	568	663	598	884	781	701
26	479	250	140	99	171	245	396	647	759	616	854	685
27	502	247	168	208	174	302	224	490	833	836	814	663
28	512	302	233	169	157	304	492	642	806	770	803	545
29	488	273	281	181	297	379	514	501	795	845	817	
30	184	327	236	119	266	445	442	584	816	854	775	
31	139		255		102	377		610		841	704	
D	389	250	190	166	220	317	446	592	704	827	790	670
M	12595	9825	6815	5772	6194	9197	13028	14272	18730	23450	24423	17445

D = average per decade; M = monthly total.

Appendix (Contd.)

1957/58	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II
1	574	533	223	239	246	327	454	435	673	820	899	616
2	407	495	306	273	281	330	465	522	607	400	898	629
3	686	498	321	262	275	254	352	610	225	810	1005	774
4	661	493	312	275	287	292	480	615	567	866	881	753
5	636	497	355	269	264	312	441	422	733	734	893	536
6	570	497	363	278	126	236	420	450	445	750	858	764
7	609	448	362	256	277	90	221	661	538	472	860	627
8	(531)	449	365	224	259	152	464	639	702	692	846	751
9	181	382	354	261	56	271	479	516	512	570	806	809
10	598	204	301	206	73	323	494	486	793	765	831	781
D	545	450	326	254	214	259	427	536	580	688	878	704
11	598	470	333	180	59	(272)	495	417	662	815	865	(620)
12	547	468	285	134	254	(190)	480	361	798	851	917	(676)
13	167	446	107	257	68	294	502	579	785	791	883	766
14	426	467	284	268	113	338	449	566	786	832	699	713
15	387	415	297	285	192	396	341	390	688	852	856	507
16	503	350	270	278	164	407	349	542	752	838	814	531
17	590	229	243	142	244	388	475	580	670	875	859	298
18	457	371	311	128	145	316	406	619	540	846	799	245
19	545	370	201	149	221	242	553	669	516	775	789	447
20	582	338	175	51	145	341	552	619	706	674	921	(516)
D	480	392	251	187	160	318	460	534	690	815	840	532

Appendix (Contd.)

1957/58	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II
21	569	275	210	145	159	400	377	199	824	(865)	839	(429)
22	424	295	264	264	207	314	552	87	736	(688)	903	700
23	571	223	293	244	267	166	561	566	822	399	916	(661)
24	545	422	253	150	313	157	139	730	599	288	809	581
25	559	380	173	186	305	306	438	727	555	263	794	741
26	554	323	245	186	326	417	379	814	642	848	820	722
27	548	278	301	255	319	442	483	711	841	840	220	746
28	537	303	302	44	221	413	568	620	854	418	738	713
29	514	187	262	122	82	420	584	664	751	(296)	467	
30	524	241	227	175	305	212	412	670	827	235	590	
31	466		238		326	376		836		884	529	
D	528	293	252	177	257	329	449	602	745	548	693	662
M	16066	11347	8536	6186	6579	9394	13365	17322	20149	21052	24804	17652

D = average per decade; M = monthly total.