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Secular variation of global irradiance in Australia

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Global irradiance measurements made at eleven Australian sites between 1928 and 1992 were analysed for evidence of secular change. Interannual variation in both annual and maximum and minimum monthly values was small and less than the accuracy of the measurements. Limitations of accuracy, together with the non-homogeneous and non-continuous nature of much of the data and the data processing procedures adopted at some periods, suggest that changes in measurement strategy are needed if secular, i.e. long-term, variations of the magnitude measured over much of the northern hemisphere are to be distinguished within a reasonable period.

Introduction

The flux of solar radiation at the earth's surface provides the energy for atmospheric circulation as well as that driving the hydrological and carbon cycles. Thus any secular changes in global irradiance K↓ would be of considerable interest for water and food supply as well as climatic change.

Until recently, interannual changes in K↓ were thought to be random and small, especially in regions with high irradiance such as Australia (Robinson 1964). More recently, analysis of the longer term series of measurements now available has shown significant decreases in K↓ at a number of sites around the world, particularly in the mid-latitudes of the northern hemisphere (Abakumova 1980; Idso 1972; Ohmura and Lang 1989; Petrosianz 1989; Russak 1990; Sekihara 1973; Stanhill and Moreshet 1992a,b; WMO 1989).

The purpose of this study was to see if any long-term changes could be observed in the fluxes of global irradiance measured in Australia.

Data analysed

Two types of data were analysed. The first comprised 84 pairs of mean monthly values. Each pair consisted of the means of two periods; the earlier of which was, in most cases, from 1957 to 1968 while the later was from 1968 to 1986. The measurements were made at seven stations of the national solar radiation network established by the Bureau of Meteorology. Details of the sites, instruments, periods of measurement and references to the data sources are given in Table 1A. None of the measurement series was homogeneous in that the instruments varied, the site coordinates showed slight changes, the duration of the two periods differed at one site, Canberra, and were only three years long at another, Sydney. Moreover, at three of the stations, Perth, Sydney and Canberra, the periods were interrupted in time.

Because of these inhomogeneities it was necessary to compare the mean values of K↓ measured in the early and in the more recent periods rather than attempt a time-trend analysis based on individual years data. This strategy was also necessary because the data reduction method adopted for the more recent period was such as to have removed any interannual variations (for details see Section 1.3.2 of the Bureau of Meteorology Corrections on p. 7 in Frick et al. 1988).

The second type of data analysed consisted of mean monthly values of K↓ taken from four series of continuous, homogeneous measurements. These were made at stations outside the national network and the data were not processed in such a way as could remove interannual variation. Details of the sites, instruments, periods of measurement and data sources are given in Table 1B.

All data presented were converted to SI units and corrected to the currently recommended World Radiometric Reference (WRR) scale (WMO 1980).

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Table 1. Details of global radiation measurements analysed.

Site	*Period analysed*	*Coordinates and elevation*	*Radiometer*↓	*Reference*
A. Paired series of observations				
Darwin	1953–1968	12°26′S, 130°52′E, 26 m	A	Kalma 1970
	1968–1986	12°25′S, 130°52′E, 35 m	D	Frick et al. 1992
Alice Springs	1953–1968	23°48′S, 133°53′E, 537 m	A	Kalma 1970
	1968–1986	23°49′S, 133°54′E, 547 m	D	Frick et al. 1992
Perth	1953–1968	31°56′S, 115°57′E, 15 m	A	Kalma 1970
	1975–1986	31°56′S, 115°58′E, 11 m	D	Frick et al. 1992
Williamtown	1953–1968	32°49′S, 151°50′E, 4 m	A	Kalma 1970
	1968–1986	32°48′S, 151°50′E, 12 m	D	Frick et al. 1992
Sydney	1957–1960	33°54′S, 151°30′E, 25 m	C	Cunningham and Sapsford 1975
	1983–1986	33°56′S, 151°10′E, 4 m	D	Frick et al. 1992
Canberra	1928–1939	35°19′S, 149°00′E, 770 m	B	Rimmer and Allen 1950
	1983–1986	35°19′S, 149°12′E, 571 m	D	Frick et al. 1992
Melbourne	1953–1967		A	Kalma 1970
[Box Hill	1953–1957	37°48′S, 145°08′E, 100 m		
East Kew	1957	37°48′S, 145°04′E, 30 m		
BoM Carlton	1958–1967	37°49′S, 144°58′E, 50 m]		
Melbourne	1967–1986		D	Frick et al. 1992
[BoM Carlton	1967–1976	37°49′S, 144°58′E, 50 m		
BoM City	1976–1986	37°49′S, 144°58′E, 123 m]		
B. Continuous series of observations				
Katherine	1969–1987	14°28′S, 132°18′E, 108 m	C	Nicholson (unpublished)
Narrabri	1971–1991	30°13′S, 149°47′E, 201 m	F,C	Hearn (unpublished)
Griffith	1968–1992	34°18′S, 146°06′E, 131 m	C	Meyer (unpublished)
Highett	1965–1978	37°57′S, 145°03′E, 48 m	E	Bannister (unpublished)

↓ *Radiometer type*

A	Robitzsch bimetallic actinograph
B	Angström thermo-electric pyranometer
C	Kipp solarimeter
D	Eppley Black and White pyranometer Model 8-48
E	Eppley model not specified
F	Rimco integrating pyranometer

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Paired series

Mean monthly values of $K\downarrow$ for the early and more recent series of measurements are presented in Table 2 for all seven sites, together with the annual totals. Changes in $K\downarrow$ between the two series are tabulated as percentage change i.e. (Late/Early × 100) − 100.

Changes in annual total irradiance are small at all seven sites. They vary from a maximum increase of 3.2 per cent at Darwin to a maximum decrease of 3.3 per cent at Melbourne and average less than 1 per cent for all sites. Expressed as a mean change per year, the maximum differences between the earlier and more recent periods are less than one per thousand per year.

Monthly differences are somewhat larger and, as can be seen from the plot of the more recent against the earlier mean monthly values in Fig. 1, suggest a small midsummer increase and midwinter decrease in irradiance. This is also shown by the below zero offset values in the linear regressions calculated separately for each site (except Darwin) and for the pooled data (Table 3). The tabulated parameters of the linear regressions indicate a six per cent increase in $K\downarrow$ between the two periods for December and January and a four per cent decrease from July to September. The statistics of the pooled regression given in Table 3 show that the slope is significantly greater than unity although the intercept does not significantly differ from zero. Monthly values of $K\downarrow$ measured at the same site in the two periods are very significantly ($P = 0.001$) correlated; 95 per cent of

Table 2. Mean global irradiance MJ m^{-2} day^{-1}.

Site *Period*	*Darwin* *53-68-86*	*Alice Springs* *53-68-86*	*Perth* *53-68 75-86*	*Williamtown* *53-68-86*	*Sydney* *57-60 83-86*	*Canberra* *28-39 83-86*	*Melbourne* *53-57-86*
January	18.3 20.1	26.6 27.3	27.8 29.2	22.5 23.8	22.0 24.3	25.3 27.6	24.9 24.2
Change %	9.7	3.5	5.1	5.9	10.7	9.0	−2.7
February	19.4 20.2	26.1 25.5	25.5 25.5	20.5 21.0	19.4 20.0	22.3 24.3	21.7 21.6
Change %	4.2	−2.3	0.0	2.2	2.9	8.8	0.0
March	20.5 20.1	23.8 23.8	21.0 21.3	18.1 18.4	16.9 17.6	18.1 19.4	16.9 16.0
Change %	−2.0	0.0	1.6	1.4	3.9	7.1	−5.3
April	19.9 22.3	19.9 20.7	14.6 15.2	13.8 14.7	12.9 13.1	14.1 13.9	11.7 11.0
Change %	12.3	3.8	4.2	6.5	1.8	−1.2	−6.2
May	20.0 20.4	16.2 16.3	11.1 10.8	10.7 10.9	10.5 9.8	10.8 10.0	7.6 7.4
Change %	1.9	0.0	−2.9	1.5	−6.5	−7.4	−2.3
June	19.8 19.7	15.3 14.9	9.1 8.8	9.2 9.1	8.4 8.4	8.4 8.9	6.6 5.9
Change %	−0.1	−2.5	−3.4	0.0	0.1	6.1	−11.0
July	20.5 20.5	16.7 15.6	10.1 9.5	10.9 10.6	9.1 8.8	9.3 8.6	7.0 6.7
Change %	−0.2	−6.8	−5.5	−2.5	−3.4	−7.8	−4.0
August	22.7 22.1	20.0 18.8	13.7 12.3	13.4 14.0	12.0 12.5	12.4 11.5	10.0 9.1
Change %	−2.7	−6.0	−10.2	4.2	3.9	−7.2	−8.7
September	23.9 23.6	23.5 22.5	17.3 16.8	17.8 17.2	15.7 16.0	17.4 16.3	14.0 12.6
Change %	−1.2	−4.4	−3.1	−3.1	2.2	−6.6	−10.2
October	23.9 24.7	25.3 25.4	22.8 21.9	21.4 20.4	19.3 19.3	20.5 20.8	18.1 17.4
Change %	3.5	0.0	−3.8	−4.7	−0.2	1.7	−3.6
November	23.4 24.1	26.5 27.1	26.5 25.3	24.2 23.5	22.9 21.2	24.3 25.1	21.1 21.0
Change %	3.0	2.3	−4.6	−2.8	−7.4	3.3	0.0
December	20.2 22.7	26.6 28.0	28.5 28.3	23.5 25.2	22.3 24.8	26.1 26.7	23.1 23.7
Change %	12.4	5.4	0.0	9.7	−11.0	2.5	2.4
Annual total GJ m^{-2}	7.682 7.925	8.098 8.087	6.920 6.829	6.258 6.345	5.816 5.951	6.347 6.469	5.544 5.359
Change %	3.2	−0.1	−1.3	1.4	2.3	1.9	−3.3

Fig. 1 **Changes in irradiance at seven sites (mean monthly values MJ m^{-2} day^{-1}). Individual sites identified by first letter of name; solid line represents the equation fitted to all data whose parameters are given in Table 3.**

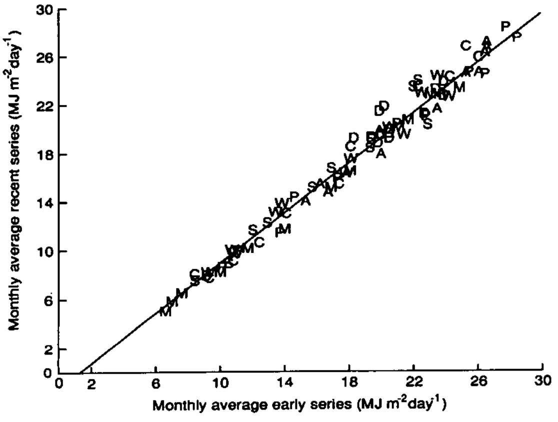


Table 3. Parameters of linear regression of more recent (Y) on earlier (X) monthly mean values of global irradiance MJ m^{-2} day^{-1}.

Site	*Slope*	*Intercept* *MJ m^{-2} day^{-1}*	*Coefficient of determination* r^2
Darwin	0.772	5.47	0.691
Alice Springs	1.089	−2.01	0.975
Perth	1.027	−0.76	0.989
Williamtown	1.020	−0.10	0.979
Sydney	1.077	−0.86	0.966
Canberra	1.117	−1.70	0.986
Melbourne	1.025	−0.89	0.995
All Sites	1.048 ± 0.017	−0.768 ± 0.932	0.978

the total (i.e. site and month) variation in $K\downarrow$ for the more recent period is accounted for by the variation in the earlier period.

The distribution of changes in mean monthly values is shown in Fig. 2; the mean monthly change, an increase of 0.03 per cent over the 17-year average between the midpoints of the two series of measurement, has a sample standard deviation of 5.33 per cent.

Fig. 2 Distribution of changes in mean monthly values of irradiance at seven sites, percentage (example: class centred on 4.5 refers to 4.1–5.0 per cent inclusive).

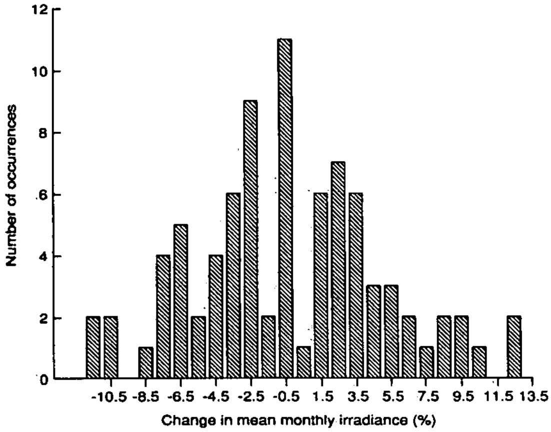
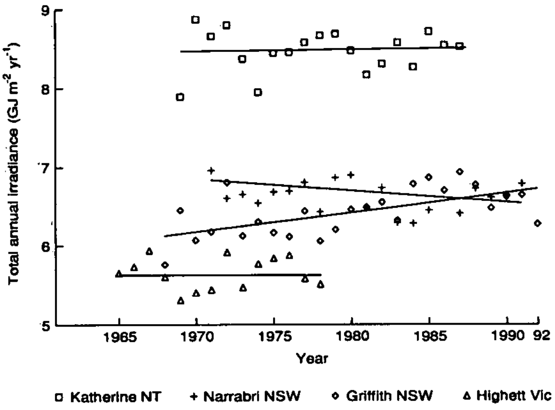


Fig. 3 Secular variation in total annual irradiance at four sites with continuous series of measurement, GJ m^{-2} yr^{-1}. Lines represent the fitted linear equations whose parameters are given in Table 4.



Continuous series

Four series of continuous measurements of global irradiance were available that had not been processed to remove any interannual changes. This allowed a more rigorous test of any secular trends that may have occurred.

Annual values of total yearly irradiance and the midsummer and midwinter maximum and minimum monthly means (those of December and January and June and July respectively) together with their interannual variation are shown in Fig. 3 and Table 4. The mean annual values of irradiance at Katherine, Narrabri, Griffith and Highett, together with their sample standard deviations, were 23.215 ± 0.264, 18.172 ± 0.525, 17.614 ± 0.822 and 15.466 ± 0.561 MJ m^{-2} day^{-1}. None of the four series showed a large or significant secular trend. The coefficients of determination, r^2, between irradiance and year of measurement were small and not statistically significant, except in the case of Griffith, accounting for one, six, 35 and one per cent respectively of the total interannual variation for the four series. The increase in annual irradiance in the Griffith series was significant at $P = 0.10$.

Discussion and conclusions

The results presented, showing no change in irradiance in Australia, are in marked contrast to those elsewhere in the world, previously cited, which show a marked decrease in the northern hemisphere. The difference may be explained by the three-fold lower area-averaged optical depth of aerosol scatter for the southern hemisphere atmosphere calculated by Charlson et al. (1991) on the basis of the computed column burden of tropospheric SO_4 — the major radiation scattering aerosal of anthropogenic origin.

The absence of secular change in Australian irradiance is confirmed by the absence of any change in historical records of sunshine and the tentative indications that this is also the case for observations of cloudiness in Australia (Jones and Henderson-Sellers 1992).

However, the limited, and to a large extent unknown, accuracy in the values of $K\downarrow$ limits the conclusions that can be drawn from analysis of past measurements made in Australia.

A retrospective assessment of the accuracy of the first national series of $K\downarrow$ measurements made with the network of actinograph stations puts this at ±30 per cent for monthly means (Bureau of Meteorology 1979). Three times as great an accuracy was claimed for these measurements by the initiator (Albrecht 1958) and some support for his claim is provided by an authoritative text on meteorological instruments (Anon. 1956) and from a comparison between actinograph and thermoelectric pyranometer measurements made in a radiation climate similar to that of Australia (Stanhill 1965). A similar three-fold difference exists in the accuracy quoted for the later series of thermoelectric pyranometer measurements (Bureau of Meteorology 1979; Frick et al. 1992).

The accuracy of the four continuous series of solar irradiance measurements from stations outside the national network is even more difficult to assess and document. In general the pyranometers

Table 4. **Mean values of irradiance, sample standard deviations and linear dependence on year of measurement of continuous measurement series. Annual totals GJ m^{-2}, midsummer and midwinter means MJ m^{-2} day^{-1}.**

Site (for details see Table 1B)	*Irradiance*	*Sample standard deviation*	*Linear relationship with year of measurement*		
			Slope	*Intercept*	*Coefficient of determination r^2*
Katherine					
Annual GJ m^{-2} yr^{-1}	8.473	0.096	4.081×10^{-3}	0.402	0.008
Maximum MJ m^{-2} day^{-1}	25.846	0.934	0.017	−8.460	0.009
Minimum MJ m^{-2} day^{-1}	20.619	1.067	-5.263×10^{-3}	20.723	0.001
Narrabri					
Annual GJ m^{-2} yr^{-1}	6.633	0.192	-7.160×10^{-3}	20.816	0.055
Maximum MJ m^{-2} day^{-1}	25.352	1.340	-1.331×10^{-3}	27.989	0.001
Minimum MJ m^{-2} day^{-1}	10.195	0.666	-7.062×10^{-3}	24.184	0.004
Griffith					
Annual GJ m^{-2} yr^{-1}	6.429	0.300	0.024	−41.791	0.355
Maximum MJ m^{-2} day^{-1}	26.900	1.629	0.076	−124.189	0.119
Minimum MJ m^{-2} day^{-1}	8.054	1.096	0.019	−29.033	0.016
Highett					
Annual GJ m^{-2} yr^{-1}	5.645	0.205	1.174×10^{-3}	3.331	0.001
Maximum MJ m^{-2} day^{-1}	24.785	0.933	−0.025	74.224	0.012
Minimum MJ m^{-2} day^{-1}	6.865	0.438	0.021	−34.518	0.040

used were compared with substandards at relatively frequent intervals, the substandards themselves being calibrated with reference to national standards at infrequent and varying intervals of time.

Even if the most optimistic estimates of the accuracy of past measurements of K↓ in Australia are accepted as five per cent, which is close to the maximum attainable (WMO 1980), the small average annual decrease in K↓ of 0.07% yr^{-1} reported for the southern hemisphere between 1958 and 1985 (Stanhill and Moreshet 1992a) would require 70 years before this decrease exceeded the instrumental uncertainty. Such a rate of secular change would also require a 50-year period before exceeding the 3.1 per cent average coefficient of variation in annual totals of K↓ found in the four continuous series shown in Fig. 3.

The magnitude of this random interannual variation suggests that from the point of view of monitoring climate change there is little point in continuing a program of K↓ measurements at their present accuracy unless they are essential for real-time management decisions. Even this requirement could be met from estimates based on cloud cover observations giving an accuracy similar to those of the measurements themselves (Paltridge and Proctor 1976).

To monitor secular changes in K↓ of a likely magnitude within an acceptable period will require the establishment of accurate, long-term measurements at carefully selected sites. An independent and regular calibration program is essential and the direct and diffuse components of sun and sky irradiance should be included with the global total. Accompanying measurements of atmospheric turbidity and cloud cover would allow the reasons for any secular changes to be explained.

Such a strategy of measurements, emphasising accuracy and continuity, has recently been adopted by the Bureau of Meteorology and the national radiation network is now being upgraded (Forgan, personal communication). On its completion this should enable perturbations and changes in the atmospheric transmissivity of the southern hemisphere to be monitored as was done in the past at the Commonwealth Solar Observatory at Mt Stromlo in the 1930s (Rimmer 1937) and at the Aspendale Regional Radiation Centre during the 1970s (Collins 1975; Dyer 1974).

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